CONTROLLED ATMOSPHERE STORAGE OF EASTERN-GROWN PEACHES AND NECTARINES

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CONTROLLED ATMOSPHERE STORAGE OF EASTERN-GROWN PEACHES AND NECTARINES

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SUMMARY

Redhaven, Loring, and Sunhigh peaches and Late Le Grand nectarines were used in these tests. Storage temperatures of 32° and 40° F. and atmospheres with ¼, 1, 3, and 21 percent O_2 in combination with zero or 5 percent CO_2 were evaluated.

All peaches and nectarines stored 3 weeks at 40° F. and then ripened in air at 60° developed internal breakdown, regardless of the previous storage atmosphere.

After 3 weeks' storage at 32° F. the quality of most fruit was good. Differences in the quality of the fruit from the various atmospheres were small.

After 6 and 9 weeks' storage at 32° F. the quality of the fruit from 1 percent O_2 and 5 percent CO_2 was considerably better than that of fruit from air. Fruit from this atmosphere ripened with good flesh color, was softer and less grainy in texture, and had better flavor than fruit from air. Nectarines from either 1 percent or 21 percent O_2 and 5 percent CO_2 retained their flavor better than peaches from these same atmospheres. Fruit stored in air or in 1 percent O_2 with zero CO_2 at 32° F. usually failed to ripen satisfactorily when removed to air at a ripening temperature. Peaches and nectarines from zero or ¼ percent O_2 usually had a fermented flavor. In addition, those from zero percent O_2 often developed external and internal discolored areas.

Less decay generally occured in fruit from 5 percent CO_2 than in fruit from zero CO_2.

INTRODUCTION

Peaches and nectarines have a short storage life. At 31° to 32° F. the storage life of most varieties is 2 to 3 weeks, although that of a few varieties may be as long as 6 to 10 weeks.[1] When held too long at 31° to 32°, peaches fail to ripen satisfactorily on removal to a higher temperature. Such fruit does not soften normally and often becomes dry or grainy. The flesh may turn red or brown, and a watery or translucent breakdown develops about the stone. However, the external appearance of such fruit is usually quite satisfactory.

Attempts have been made to prolong the marketable life of peaches by modifying or controlling the at-

[1] Huelin, F. E., Tindale, G. B., and Trout, S. A. the cool storage of peaches in air and artificial atmospheres. Jour. Dept. Agr. Victoria 35: 609–614. 1937.

mosphere surrounding the fruit during transit or in storage. In most controlled atmospheres (CA) the carbon dioxide (CO_2) level is increased and the oxygen (O_2) level decreased from the levels occurring normally in air. Many of the early investigations on the use of CA for peaches were geared to short holding periods. Haller reviewed much of this work in 1952.[2]

In a number of these studies, increased levels of CO_2 retarded softening and color changes of peaches but increased injury and off-flavors. The precise level of CO_2 that produced these effects varied somewhat and appeared to depend upon temperature, length of exposure, variety, and stage of maturity of the fruit.

At low temperatures, reduced O_2 levels had little effect upon peaches; but at higher temperatures, the reduced O_2 levels retarded ripening.

Some investigators have reported an extended life for peaches in CA under certain conditions; others have reported a shortened life or one no longer than that for peaches from normal air-refrigerated storage. Catherine Anne peaches, for example, had a longer life in an atmosphere with 11 to 13 percent O_2 and 8 to 10 percent CO_2 than in air.[3] Later studies with other varieties indicated (1) no benefit from CA conditions over air[4] and (2) greater flavor loss in some peaches in CA conditions than in air.[5]

In recent years there has been a resurgent interest in CA storage. Also, little information is available on the behavior of many of the newer peach or nectarine varieties under CA conditions. In view of these circumstances, plus the occasional reference indicating that some beneficial effects may result from modifying the atmosphere around peaches during transit or in storage, we decided to test again the possibilities of storing peaches and nectarines in CA. These tests were conducted on some of the newer varieties, testing (1) lower O_2 levels than had previously been used, (2) a CO_2 level at which few reports of injury or off-flavors had been found, and (3) longer storage periods under CA conditions than had been used in most earlier studies.

PART I. APPEARANCE, FIRMNESS, RESPIRATION, ACIDITY, FLAVOR, AND LOW O_2 INJURY

Materials and Methods

Peach varieties Redhaven, Sunhigh, and Loring and nectarine variety Late Le Grand were used in these investigations. They were obtained on the day of harvest from commercial orchards in Maryland and Pennsylvania, brought to Beltsville, Md., and refrigerated at 32° F. The following day randomized samples of fruit were placed in the CA chambers and the atmospheres were adjusted to the test levels. Only sound fruits of uniform

[2] HALLER, M. H. HANDLING, TRANSPORTATION, STORAGE AND MARKETING OF PEACHES. U.S. Dept. Agr. Bibliog. Bul. 21. 1952.

[3] HUELIN, F. E., and TINDALE, G. B. GAS STORAGE OF PEACHES. Jour. Dept. Agr. Victoria 39: 34–38. 1941.

[4] ANTONIANI, C., MONZINI, A., and SERINI, G. THE STORAGE OF HALE PEACHES IN CARBON-DIOXIDE ENRICHED ATMOSPHERE. Ann. della Sper. Agr. (Rome) 10: 899–904. 1956.

[5] CLAYPOOL, L. L., and DAVIS, L. D. THE EFFECT OF COLD AND MODIFIED ATMOSPHERE STORAGE ON THE CANNING QUALITY OF CLING PEACHES. Food Technol. 13: 208–212. 1959.

maturity were used. Split or bruised fruits were discarded. Redhaven peaches ranged from $2\frac{1}{4}$ to $2\frac{3}{4}$ inches in diameter and other fruit varieties ranged from $2\frac{1}{2}$ to $3\frac{1}{2}$ inches. Sample sizes were 100 fruits per treatment in 1964, 50 in 1965, and 120 in 1966.

Thirty-gallon metal drums or 5-gallon wide-mouthed glass jars were used as CA chambers. Each chamber was made gastight and had two ports for gas sampling and atmosphere adjustment or for maintaining a continuous gas flow through the chambers. In 1964 a static system was used in which atmospheres were adjusted daily. Because of the difficulties encountered in maintaining very low O_2 levels, a continuous flow system, using premixed gases, was used in 1965 and 1966. Flow rates ranged from 5 to 15 liters per hour. Gas analyses were made with an Orsat-type gas analyzer, a Beckman infrared analyzer, and a Beckman paramagnetic O_2 analyzer.

Atmospheres with $\frac{1}{4}$, 1, 3, and 21 percent O_2 in combinations with zero and 5 percent CO_2 were tested. The rest of the gas in each atmosphere was nitrogen (N_2). The actual atmospheres varied somewhat from the desired levels but generally were within the following ranges: $\frac{1}{4}$ percent O_2 (0.15–0.35); 1 percent O_2 (0.7–1.5); 3 percent O_2 (2.5–3.5); 21 percent O_2 (18–21); zero CO_2 (0.0–0.3); 5 percent CO_2 (4.5–5.5). The atmosphere with 21 percent O_2 and zero CO_2 was compressed air (breathing quality). Air is referred to as 21 percent O_2 and zero CO_2 for brevity as it is understood that air normally contains slightly less than 21 percent O_2, about 78 percent N_2, and approximately 1 percent of other gases, including about 0.03 percent CO_2. In addition to fruit stored in each of these atmospheres, one lot of fruit was held in a carton in the storage room air and another in a chamber with zero O_2 and zero CO_2. A 1-pound package of fresh, dry hydrated lime was placed in each chamber with zero CO_2 to prevent a buildup of CO_2.

Redhaven peaches and Late LeGrand nectarines were used in all tests, Sunhigh in 1964 and 1965, and Loring in 1966. In 1964 the fruits were stored for 3 weeks in CA at 32° and 40° F. In 1965 and 1966 they were stored for 3, 6, and 9 weeks in CA at 32° only. After each storage period all the fruits from one CA chamber or carton per treatment were removed for evaluation. The fruits from each treatment were divided into two equal lots and measurements or observations were made on subsamples from each.

The fruits were inspected immediately after removal from storage and again after ripening in air at 60° or 65° F. In all years the relative humidity of the ripening room was 90 percent. At removal from storage and after ripening, observations were made on the external and internal appearance of the fruit and fruit firmness was measured. During the ripening period, respiration of the fruit in air was measured. After ripening, acidity and flavor were evaluated.

Internal flesh color and texture (graininess) were rated on 20-fruit samples in 1966. After ripening, fruits from each lot were cut in half at right angles to the suture. Each pair of halves was then rated for color and texture on a scale of 5 to 1 (5-excellent, 4-good, 3-fair, 2-poor, and 1-very poor). A total score for color or texture was obtained for each lot of fruit by multiplying the number of fruits in each category by the numerical rating and adding these numbers.

Fruit firmness was measured with a Magness-Taylor pressure tester using a $\frac{5}{16}$-inch plunger on the cut surfaces of opposite cheeks of 5 or 10 fruits.

Respiration was measured in air

at 60° or 65° F. for a 2- or 3-day period. The technique used was a modification of Method II as described by Denny.[6] Fruit temperature and internal atmosphere were allowed to equilibrate in air at the respiration temperature for 24 hours before CO_2 collection was begun. The respiration of duplicate samples of five fruits per treatment was measured. The CO_2 given off was absorbed in a potassium hydroxide (KOH) solution, the carbonate precipitated with barium chloride ($Ba\ Cl_2$), and the solution titrated against standardized hydrochloric acid (HCl).

Acidity, expressed as malic acid, was determined on the fruit used for the firmness measurements. Opposite quarters were ground in a Waring blender, 25-gram aliquots were diluted to 100 milliliters with distilled water, and the solution was titrated to pH 7.0.

A taste panel evaluated the flavor of both fresh and frozen samples of fruit in 1964. When the fruit was prepared for freezing, a 1 percent ascorbic acid solution was added to the sliced fruit to reduce browning. The ascorbic acid may have partly masked the flavor, so in 1965 and 1966 only freshly sliced fruit was evaluated by the taste panel.

Most of the data were analyzed as randomized complete blocks and means compared by Duncan's multiple range test.

Results and Discussion for 1964 Tests

40° F. Storage

After 3 weeks' storage at 40° F. and a ripening period of 3 or 4 additional days in air at 60°, the external appearance of fruit from all atmospheres was good. Internally, however, none of the fruit from any atmosphere, air included, had a satisfactory appearance. The flesh in many fruits became dry, grainy, and somewhat fibrous. In some fruits flesh adjacent to the skin broke down and in others the flesh adjacent to the stone was mushy and translucent. Figure 1 shows the internal appearance of nectarines after 3 weeks' storage at 32° and 40° and ripening at 60°.

The effects of the atmospheres during 40° F. storage on fruit firmness were very pronounced (table 1). Fruits from ¼ percent O_2 remained most firm, and firmness decreased as the O_2 level increased. Also, at any given level of O_2, the fruits remained more firm if held in 5 percent CO_2 than if held in zero CO_2.

Respiration during ripening at 60° F. was usually lowest by fruits from ¼ percent O_2. CO_2 in the storage atmosphere also retarded subsequent respiration by the fruit in air.

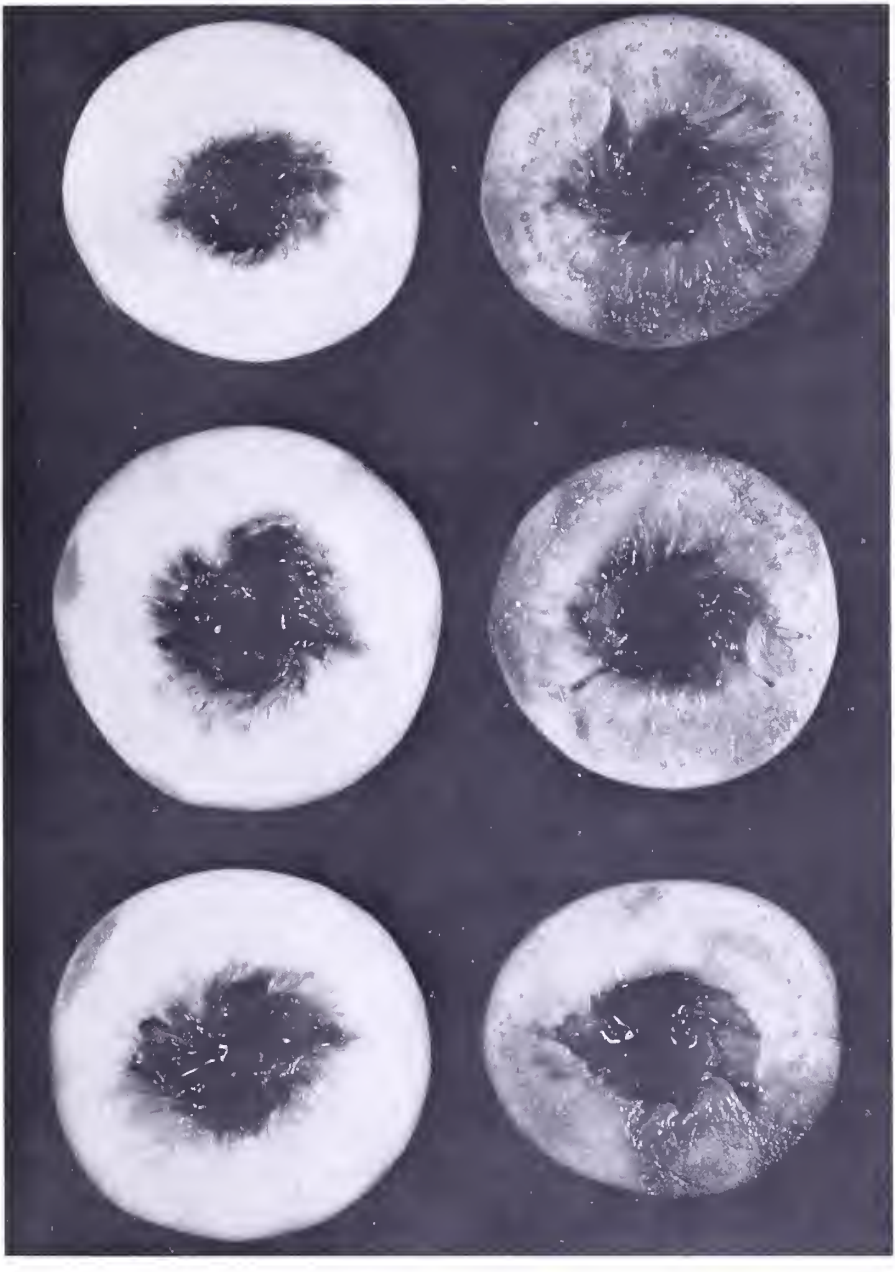
Flavor of the fruit from the 40° F. storage was not evaluated because the very poor internal appearance of the fruit precluded its marketability. Use of 40° was dropped in 1965 and 1966.

32° F. Storage

After 3 weeks' storage at 32° F., appearance and firmness of fruits from all the atmospheres did not differ appreciably. All ripened satisfactorily at 60°, became juicy, and developed normal external and internal color.

Differences in respiration during ripening were small. Fruits from atmospheres with 5 percent CO_2 generally produced slightly less CO_2 than those from zero CO_2. The authors judged flavor after fruits ripened. Some fruits from ¼ percent O_2, with or without CO_2, had a slightly

[6] Denny, F. E. suggested methods for measuring the carbon dioxide production of a large number of simultaneous samples. Boyce Thompson Inst. Contrib. 15:141–151. 1948.



32° 40°

FIGURE 1.—Nectarines after 3 weeks in air at 32° or 40° F. plus a ripening period in air at 60°.

TABLE 1.—*Firmness of peaches and nectarines after storage at 40° F. for 3 weeks (1964)*[1]

Percent CO_2 during storage	Firmness of fruit from O_2 level of—				CO_2 mean
	¼ percent	1 percent	3 percent	21 percent	
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*
0	7.9 ab	5.4 bcd	3.6 cd	2.6 d	4.9 b
5	8.6 a	7.4 ab	6.7 abc	5.1 bcd	7.0 a
O_2 mean	8.3 a	6.4 ab	5.2 b	3.9 c	

[1] Each value in main block (inside heavy lines) is the mean of 1 sample of 10 fruit from each of 3 varieties. Values in each block followed by the same letter or letters do not differ significantly at the 1-percent level.

fermented flavor. Flavor of the fruit from all other treatments was acceptable at this time. When the formal taste panel evaluated the flavor of the frozen samples the next spring, they did not prefer fruit from any single treatment. Their ratings, however, indicated a slight preference for fruit from 5 percent CO_2 over fruit from zero CO_2.

Since differences between fruit from the various atmospheres were so small in this test, longer storage periods were included in 1965 and 1966 to determine whether these differences would diverge further with time in storage.

Results and Discussion for 1965 and 1966 Tests

Results of the 1965 and 1966 tests were similar and are discussed together. Where comparable observations or measurements were made, the data were combined in the statistical analyses. Atmospheres with 3 percent O_2 were omitted in 1966 because in 1965 fruit response at this O_2 level was similar to that of fruit from 21 percent O_2. Results for air-stored fruit in cartons or in chambers were the same, so only data from the treatments in chambers are presented.

Appearance

EXTERNAL FRUIT CONDITION.—The external appearance of fruit from all atmospheres was good after 3, 6, or 9 weeks' storage at 32° F. followed by a ripening period of 3 or 4 additional days in air at 65°.

INTERNAL FRUIT CONDITION.—The flesh of all fruits appeared normal when they were removed from storage after 3, 6, or 9 weeks. After a ripening period of 3 or 4 additional days in air at 65° F., the internal condition of the fruit usually differed, depending upon the previous storage atmosphere. The differences were especially pronounced in fruit stored 6 or 9 weeks. After 6 or 9 weeks' storage, most fruits from atmospheres with ¼ percent O_2 and zero CO_2 and all fruits from other O_2 levels and *with* 5 percent CO_2 ripened satisfactorily. Most fruits were juicy and had a good, yellow flesh color, a smooth texture, and little flesh breakdown. However, fruits from either 1 percent or 21 percent O_2 with zero CO_2 ripened poorly. Many had a dry, grainy texture, badly discolored flesh, or a watery, translucent breakdown about

the stone. Also, after ripening the flesh of many nectarines from zero CO_2 adhered to the stone, but the flesh of nectarines from 5 percent CO_2 usually came free of the stone. This was most pronounced in fruits from 1 percent and 21 percent O_2. Plate 1 shows the internal appearance of some of these fruits.

Although most peaches and nectarines were not injured when stored in ¼ percent O_2 and zero CO_2, a few Loring peaches in the 1966 tests developed a grayish breakdown after 9 weeks in this atmosphere. The appearance of the disorder was similar to the internal injury observed in fruit held in zero O_2 (plate 2).

After ripening the flesh color of fruits from the various atmospheres was similar in 1965 and 1966, but it was scored as described under "Materials and Methods" only in 1966 (table 2). Under this scoring method, the flesh color score was significantly lower for fruit after 6 and 9 weeks' storage in either 1 percent or 21 percent O_2 and zero CO_2 than the score for fruit from other atmospheres. This lower score was due primarily to the severe discoloration in Redhaven and Loring peaches (table 3). Flesh color in nectarines from all atmospheres was excellent during 6 weeks' storage. After 9 weeks' storage the flesh color of nectarines from either 1 percent or 21 percent O_2 and zero CO_2 showed a marked deterioration.

The method used to score grainy or mealy texture was similar to that used to score flesh color. Graininess increased much more rapidly in fruits from either 1 percent or 21 percent O_2 and zero CO_2 than in fruits from other atmospheres (table 4). Fruit with a graininess score of 75 or lower probably would be marketable, but this condition, combined with other undesirable qualities, such as poor flesh color, would further reduce the marketability of the fruit.

Firmness

The rate at which peaches and nectarines soften is important in the ripening process of these fruits. The rate of softening for fruit in 1965 and 1966 was determined by measuring firmness of fruit (1) at harvest (table 5); (2) immediately after remova

TABLE 2.—*Flesh color score of peaches and nectarines after ripening in air at 65° F. following storage at 32° (1966)* [1]

Storage atmosphere		Flesh color score of fruit stored for—			Mean score
O_2 (*percent*)	CO_2 (*percent*)	3 weeks	6 weeks	9 weeks	
¼	0	98 a	93 a	97 a	96 a
¼	5	98 a	97 a	99 a	98 a
1	0	95 a	71 b	61 b	76 b
1	5	95 a	93 a	96 a	95 a
21	0 (air)	90 ab	70 b	62 b	74 b
21	5	97 a	94 a	91 a	94 a

[1] Each score in main block (inside heavy lines) is the mean of 6 samples of 20 fruit each. A score of 100 indicates excellent flesh color; lower scores indicate increasingly greater discoloration. Scores in each block followed by the same letter or letters do not differ significantly at the 1-percent level.

LORING PEACHES after 9 weeks in 21 percent O_2 with zero CO_2 (air) (*left*) and with 5 percent CO_2 (*right*);

REDHAVEN PEACHES after 6 weeks in 1 percent O_2 with zero CO_2 (*left*) and with 5 percent CO_2 (*right*);

LATE LE GRAND nectarines after 6 weeks in 21 percent O_2 with zero CO_2 (air) (*left*) and with 5 percent CO_2 (*right*). Note flesh adhering to stone of nectarine stored without CO_2 (*left*).

Internal appearance of peaches and nectarines after storage at 32° F. plus 4 days in air at 65°.

SUNHIGH PEACH

LATE LE GRAND NECTARINE

LORING PEACH
External view (*left*); internal view (*right*).

External and internal injuries found on peaches and nectarines after storage in zero O_2 and zero CO_2 at 32° F. plus 4 days in air at 65°.

TABLE 3.—*Flesh color score of peach and nectarine varieties after ripening in air at 65° F. following storage at 32° (1966)* [1]

Fruit tested and storage atmosphere		Flesh color score of fruit stored for—			Mean score
O_2 (*percent*)	CO_2 (*percent*)	3 weeks	6 weeks	9 weeks	
Redhaven peaches:					
¼	0	95	88	92	92
¼	5	98	97	99	98
1	0	92	53	68	71
1	5	94	82	93	90
21	0 (air)	81	57	73	70
21	5	98	83	97	93
Loring peaches:					
¼	0	98	92	100	97
¼	5	96	95	99	97
1	0	94	62	52	69
1	5	93	98	96	96
21	0 (air)	89	54	55	66
21	5	94	98	80	91
Late Le Grand nectarines:					
¼	0	100	100	100	100
¼	5	100	100	100	100
1	0	100	100	64	88
1	5	100	100	100	100
21	0 (air)	100	100	58	86
21	5	100	100	97	99

[1] Each score in main blocks (inside heavy lines) is the mean of 2 samples of 20 fruit each. A score of 100 indicates excellent flesh color; lower scores indicate increasingly greater discoloration.

TABLE 4.—*Graininess score of the flesh of peaches and nectarines after ripening in air at 65° F. following storage at 32° (1966)* [1]

Storage atmosphere		Graininess score of fruit stored for—			Mean score
O_2 (*percent*)	CO_2 (*percent*)	3 weeks	6 weeks	9 weeks	
¼	0	100 a	93 a	92 a	95 a
¼	5	100 a	99 a	95 a	98 a
1	0	95 a	68 ede	66 de	76 b
1	5	97 a	90 ab	85 abcd	91 a
21	0 (air)	87 abe	63 e	71 bede	74 b
21	5	95 a	90 ab	87 abc	91 a

[1] Each score in main block (inside heavy lines) is the mean of 6 samples of 20 fruit each. A score of 100 indicates no graininess; 75 or below, severe graininess. Scores in each block followed by the same letter or letters do not differ significantly at the 1-percent level.

from 32° storage (table 6); and (3) after ripening in air at 65° (tables 7 and 8).

Fruit firmness at harvest is given in table 5. Fruit held at 65° F. immediately after harvest softened to 1 or 2 pounds in 3 or 4 days.

TABLE 5.—*Firmness of 3 peach varieties and 1 nectarine variety at harvest*

Variety	Year	
	1965	1966
	Pounds	*Pounds*
Redhaven peach	11.2	7.7
Sunhigh peach	8.5	----
Loring peach	----	8.9
Late Le Grand nectarine.	5.7	11.5

Fruits were slightly softer after removal from 32° F. storage, than they had been at harvest. Fruits from atmospheres with $^1/_4$ percent O_2 were firmer than those from either 1 percent or 21 percent O_2; whereas fruits from 5 percent CO_2 were firmer than those from zero CO_2 (table 6). The latter finding agrees with other reports; CO_2 retards softening of peaches.[7]

During ripening in air at 65° F., peaches and nectarines from 5 percent CO_2 softened more rapidly than fruit from zero CO_2 (table 7). Actually fruit from 5 percent CO_2 softened much like unstored or freshly harvested fruit. The effects of CO_2 in the storage atmosphere on the subsequent softening of fruit are more striking if one compares these effects after different times in storage (table 8). After 3 weeks' storage, fruit from all atmospheres softened to about the same degree when held in air at 65°. After 6 or 9 weeks' storage, differences in softening between fruit from 5 percent CO_2 and zero CO_2 became increasingly greater. The softest fruit in every case were from 5 percent CO_2 during storage. Apparently CO_2 in the storage atmosphere tended to nullify or at least reduce the adverse effects of low temperature on the subsequent softening of these fruits on removal to air at a higher temperature.

[7] See footnote 2, page 2.

Respiration

The rate of respiration of a commodity is often used as a measure of its rate of deterioration; that is, the more rapid the rate of respiration, the more rapid the rate of deterioration. In the tests reported here, CO_2 production by the fruit in air at 65° F. after removal from CA storage was used to measure the rate of respiration. Both the O_2 and the CO_2 levels of the storage atmosphere affected CO_2 production (table 9). Respiration was lower by fruits from 5 percent CO_2 than by fruits from zero CO_2 except in $^1/_4$ percent O_2. The rate of respiration increased with the level of O_2 in the storage atmosphere.

Titratable Acidity

At all O_2 levels, acidity decreased with time in storage, but it decreased less in fruit from atmospheres with 5 percent CO_2 than in fruit from zero CO_2 (table 10). Fruit from either 1 percent or 21 percent O_2 and zero CO_2 were the least acid of all fruits tested.

Although we did not try to relate acidity to flavor preferences, perhaps there is a relationship because an occasional taste panelist did make note of the bland flavor of some fruit. These fruits generally were from zero CO_2. Since acidity decreased during storage, any treatment reducing this loss would also reduce quality deterioration.

Flavor

In the 1965 test, flavor was evaluated by the authors and two or three

TABLE 6.—*Firmness of peaches and nectarines after storage at 32° F. for 3, 6, and 9 weeks (1965 and 1966)* [1]

Percent CO_2 during storage	Firmness of fruit from O_2 level of—			CO_2 mean
	¼ percent	1 percent	21 percent	
	Pounds	*Pounds*	*Pounds*	*Pounds*
0	8.9 ab	8.2 bc	7.5 c	8.2 b
5	9.4 a	8.8 ab	8.3 bc	8.8 a
O_2 mean	9.2 a	8.5 b	7.9 b	

[1] Each value in main block (inside heavy lines) is the mean of 36 samples of 5 or 10 fruit each. Values in each block followed by the same letter or letters do not differ significantly at the 1-percent level.

TABLE 7.—*Firmness of peaches and nectarines after ripening in air at 65° F. following storage at 32° for 3, 6, and 9 weeks (1965 and 1966)* [1]

Percent CO_2 during storage	Firmness of fruit from O_2 level of—			CO_2 mean
	¼ percent	1 percent	21 percent	
	Pounds	*Pounds*	*Pounds*	*Pounds*
0	2.8 ab	3.0 a	2.6 ab	2.8 a
5	2.1 ab	2.0 b	2.1 ab	2.1 b
O_2 mean	2.5 a	2.5 a	2.3 a	

[1] Each value in main block (inside heavy lines) is the mean of 36 samples of 5 or 10 fruit each. Values in each block followed by the same letter or letters do not differ significantly at the 1-percent level.

TABLE 8.—*Firmness of peaches and nectarines after ripening in air at 65° F. following storage at 32° (1965 and 1966)* [1]

Storage atmosphere		Firmness of fruit stored for—			Mean value
O_2 (*percent*)	CO_2 (*percent*)	3 weeks	6 weeks	9 weeks	
		Pounds	*Pounds*	*Pounds*	*Pounds*
¼	0	1.9 cd	2.0 cd	4.6 a	2.8 ab
¼	5	1.8 d	1.7 d	2.9 bcd	2.1 ab
1	0	1.9 cd	2.5 bcd	4.8 a	3.0 a
1	5	1.6 d	1.6 d	2.6 bcd	2.0 b
21	0 (air)	2.1 bcd	2.2 bcd	3.5 abc	2.6 ab
21	5	1.9 cd	1.6 d	2.8 bcd	2.1 ab

[1] Each value in main block (inside heavy lines) is the mean of 12 samples of 5 or 10 fruit each. Values in each block followed by the same letter or letters do not differ significantly at the 1-percent level.

TABLE 9.—*CO_2 production by peaches and nectarines after ripening in air at 65° F. following storage at 32° for 3, 6, and 9 weeks (1965 and 1966)* [1]

Percent CO_2 during storage	CO_2 production by fruit from O_2 level of—			CO_2 mean
	¼ percent	1 percent	21 percent	
	Mg./kg./hr.	*Mg./kg./hr.*	*Mg./kg./hr.*	*Mg./kg./hr.*
0	53 d	59 ab	62 a	58 a
5	53 d	54 cd	57 bc	55 b
O_2 mean	53 c	56 b	59 a	

[1] Each value in main block (inside heavy lines) is the mean of 36 samples of 5 fruit each. Values in each block followed by the same letter or letters do not differ significantly at the 1-percent level.

TABLE 10.—*Titratable acidity of peaches and nectarines after ripening in air at 65° F. following storage at 32° (1965 and 1966)* [1]

Storage atmosphere		Acidity of fruit stored for—			Mean value
O_2 (*percent*)	CO_2 (*percent*)	3 weeks	6 weeks	9 weeks	
		Mg./100 g.	*Mg./100 g.*	*Mg./100 g.*	*Mg./100 g.*
¼	0	586 a	498 abcde	484 bcdef	522 ab
¼	5	584 a	558 abc	531 abcd	557 a
1	0	561 abc	423 ef	403 f	462 c
1	5	568 ab	515 abcd	520 abcd	534 a
21	0 (air)	505 abcde	455 def	415 ef	459 c
21	5	561 abc	505 abcde	469 cdef	512 ab

[1] Each value in main block (inside heavy lines) is the mean of 6 samples of 5 or 10 fruit each. Values in each block followed by the same letter or letters do not differ significantly at the 1-percent level.

staff members not involved in the test. All fruit evaluated was ripened after removal from storage. Samples of two to four fruits per treatment were tasted and each person tasted at least one slice per fruit. The primary objective in this taste test was to determine whether any fermented flavors developed in fruit from any atmosphere.

All tasters detected fermented flavors in some fruit from atmospheres with ¼ percent O_2 after 9 weeks' storage, but only an occasional taster detected this flavor after 3 or 6 weeks' storage. Fermented flavors were not detected in fruit with 1 percent O_2 or more. Although none of the fruits were rated high in flavor at the end of 6 or 9 weeks, most tasters preferred fruit from 5 percent CO_2.

In the 1966 test, flavor was evaluated more critically by a panel of five persons not involved in the test.

All fruit evaluated were ripened for 6 to 7 days at 65° F. after removal from storage, and each panelist tasted a slice of eight fruits from each atmosphere over a period of 2 days and four sittings. Flavor was rated on a 7-point hedonic scale from 7 (like very much) to 1 (dislike very much).

After 3 weeks' storage, differences in flavor preference between Redhaven and Loring peaches were small from either 1 percent or 21 percent O_2, regardless of CO_2 level. Flavor of peaches from all these lots was acceptable (table 11). Peaches from $^1/_4$ percent O_2, however, were rated low because of a fermented or wine-like flavor. Flavor ratings usually decreased as time in storage increased; but after 9 weeks' storage, peaches from 1 percent O_2 and 5 percent CO_2 were rated higher than those from any other atmosphere tested.

Nectarines from either 1 percent or 21 percent O_2 and 5 percent CO_2 retained their flavor through 9 weeks.

TABLE 11.—*Flavor ratings of peaches and nectarines after ripening in air at 65° F. following storage at 32° (1966)* [1]

Fruit tested and storage atmosphere		Flavor of fruit stored for [2]—			Mean rating [3]
O_2 (*percent*)	CO_2 (*percent*)	3 weeks	6 weeks	9 weeks	
Redhaven peaches:					
$^1/_4$	0	2.9 efgh	4.2 bcd	2.5 fgh	3.2 b
$^1/_4$	5	2.3 gh	3.5 de	2.2 h	2.7 c
1	0	4.5 bc	3.2 ef	3.0 ef	3.6 b
1	5	4.5 bc	4.8 ab	4.4 bc	4.6 a
21	0 (air)	4.6 abc	3.1 ef	3.2 ef	3.7 b
21	5	5.3 a	4.2 bcd	3.9 cd	4.5 a
Loring peaches:					
$^1/_4$	0	3.3 ef	3.9 cde	2.3 g	3.2 d
$^1/_4$	5	3.6 def	3.7 de	3.4 def	3.6 cd
1	0	5.1 a	4.0 cde	3.4 def	4.1 abc
1	5	5.0 ab	4.8 ab	4.2 bcd	4.7 a
21	0 (air)	5.3 a	4.2 bcd	3.7 de	4.4 ab
21	5	4.7 abc	4.0 cde	2.8 fg	3.8 bc
Late Le Grand nectarines:					
$^1/_4$	0	3.9 bcd	4.1 abcd	3.8 cd	3.9 b
$^1/_4$	5	4.8 abc	4.4 abcd	3.8 cd	4.3 ab
1	0	5.1 a	3.7 cd	3.5 d	4.1 b
1	5	5.1 a	5.1 a	5.0 ab	5.1 a
21	0 (air)	4.3 abcd	3.8 cd	3.7 cd	3.9 b
21	5	5.1 a	5.2 a	5.0 ab	5.1 a

[1] Rated from 7 (like very much) to 1 (dislike very much). Each value in main blocks (inside heavy lines) is the mean of 40 to 48 individual taste evaluations.

[2] Ratings in each main block followed by the same letter or letters do not differ significantly at the 5-percent level.

[3] Mean ratings followed by the same letter or letters do not differ significantly at the 1-percent level.

Fermented flavors were noted in fruit from ¼ percent O_2 but these flavors were not as objectionable in nectarines as they were in peaches.

Low O_2 Injury

The zero O_2–zero CO_2 treatment was added to these tests to produce O_2 deficiency symptoms. Similar symptoms occurring in any of the low O_2 treatments would help to identify the level at which O_2 becomes deficient.

Externally, fruit from zero O_2 developed various types of skin browning (plate 2). Sunhigh and Loring peaches developed an intense skin browning that was sharply delineated from adjacent healthy appearing skin. Redhaven peaches developed a skin browning that appeared more diffuse and not as dark as that on Sunhigh or Loring. Late Le Grand nectarines developed a black pitting of the skin.

Internally, injuries in fruit from zero O_2 levels were well defined in Sunhigh and Loring peaches. In these varieties the injury appeared as a grayish-brown breakdown surrounding the stone (plate 2). This same type of injury occurred in some Loring peaches from ¼ percent O_2 and zero CO_2. Very little internal injury occurred in either Redhaven peaches or Late Le Grand nectarines from zero O_2. When such injuries did occur, they too appeared as a breakdown surrounding the stone.

Fruit of all varieties tested developed a fermented or winelike flavor in zero O_2.

Part II. DECAY

Materials and Methods

Decay was evaluated on peaches and nectarines stored at 32° F. in atmospheres with ¼, 1, and 21 percent O_2, with and without 5 percent CO_2. One lot of fruit in each atmosphere was not inoculated, the other was inoculated by dipping the fruit in beef-peptone broth containing spores of *Monilinia fructicola* (Wint.) Honey (brown rot organism). After inoculation, excess broth was drained from the fruits and they were held at 32° overnight and then placed in the different atmospheres. The percentage of decayed fruits was determined when the fruits were removed from storage and after ripening in air at 65° F. and 90 percent relative humidity. The experiment was conducted with two varieties of peaches and one variety of nectarines for 2 years.

Results and Discussion

Decay When Removed From Storage

UNINOCULATED FRUIT.—Uninoculated fruit developed no decay or only a trace of decay during 3 and 6 weeks' storage, regardless of atmosphere. When the fruit was removed after 9 weeks' storage in atmospheres with either 1 percent or 21 percent O_2 and with zero CO_2, a moderate amount of decay was present (table 12). Decay was somewhat less on fruit from 1 percent O_2 than from 21 percent O_2. At both these O_2 levels, decay was less on fruit from 5 percent CO_2 than from zero CO_2. Decay was negligible on fruit from ¼ percent O_2.

INOCULATED FRUIT.—Inoculated fruit developed no decay during 3 weeks' storage and only a trace amount during 6 weeks' storage,

TABLE 12.—*Decay of peaches and nectarines after storage at 32° F. for 9 weeks (1965 and 1966)* [1]

Storage atmosphere		Decay of—	
O_2 (*percent*)	CO_2 (*percent*)	Uninoculated fruit [2]	Inoculated fruit [3]
		Percent	*Percent*
¼	0	0.0 a	0.8 a
¼	5	.3 a	.3 a
1	0	5.8 ab	21.8 b
1	5	1.1 a	9.7 ab
21	0 (air)	10.7 b	45.0 c
21	5	2.3 a	6.3 a

[1] Values in each column followed by the same letter or letters do not differ significantly at the 5-percent level.

[2] Each value is the mean of 6 tests with 25 fruit examined in 1965 and 100 fruit in 1966 for each test and each atmosphere.

[3] Each value is the mean of 6 tests with 50 fruit examined for each test and each atmosphere.

regardless of atmosphere. When decay developed during 6 weeks' storage, it was less on fruit from 5 percent CO_2 than on fruit from zero CO_2. When the fruit was removed after 9 weeks' storage, decay was severe on fruit from some atmospheres (table 12). At either 1 percent or 21 percent O_2 levels, decay was less on fruit from 5 percent CO_2 than on fruit from zero CO_2. Decay was less on fruit from ¼ percent O_2 than on fruit from other atmospheres.

Decay During Ripening

UNINOCULATED FRUIT.—During 4 days' ripening, no decay or only a trace of decay developed on uninoculated fruit previously stored in controlled atmospheres for 3 weeks (table 13.) Considerable decay developed on fruit stored in most controlled atmospheres for 6 and 9 weeks. More decay developed on fruit previously stored for 9 weeks than on fruit stored for 6 weeks. Although differences between fruit stored in different atmospheres were not significant, somewhat less decay developed on fruit from atmospheres with ¼ percent O_2 than on fruit from higher levels of O_2.

INOCULATED FRUIT.—During 4 days' ripening, decay on inoculated fruit was related to the storage atmosphere and to the length of time in storage (table 14). After 3 weeks' storage, decay was significantly greater on fruit stored in air (21 percent O_2–zero CO_2) than on fruit stored in any of the other atmospheres. After 6 and 9 weeks' storage, only fruits from ¼ percent O_2 consistently had significantly less decay than fruits from air. The percentage of decay usually increased as the length of the storage period increased, regardless of the atmosphere in which the fruit was stored.

Both O_2 and CO_2 affected decay of inoculated fruits (table 15). Fruits from ¼ percent O_2 developed less decay than fruits from either 1 percent or 21 percent O_2, regardless of the CO_2 level. Fruits from 5 percent CO_2 developed less decay than fruits from zero CO_2.

After 6 days' ripening at 65° F., fruits from ¼ percent O_2 developed

TABLE 13.—*Decay of uninoculated peaches and nectarines held in air for 4 days at 65° F. after storage at 32° (1966)* [1]

Storage atmosphere		Decay of fruit stored for—		
O_2 (*percent*)	CO_2 (*percent*)	3 weeks	6 weeks	9 weeks
		Percent	*Percent*	*Percent*
¼	0	0.5	0.7	11.3
¼	5	0	4.0	6.3
1	0	.5	7.7	12.7
1	5	0	8.0	8.7
21	0 (air)	.5	10.0	16.7
21	5	.5	12.0	26.0

[1] Each value is the mean of tests with 70 to 80 fruit examined for each variety (except one variety in the 3 weeks' storage) in each atmosphere and in each removal period. Differences between values are not significant at the 5-percent level.

TABLE 14.—*Decay of inoculated peaches and nectarines held in air for 4 days at 65° F. after storage at 32° (1965 and 1966)* [1]

Storage atmosphere		Decay of fruit stored for—		
O_2 (*percent*)	CO_2 (*percent*)	3 weeks	6 weeks	9 weeks
		Percent	*Percent*	*Percent*
¼	0	29 ab	29 a	57 a
¼	5	24 a	13 a	49 a
1	0	38 ab	68 cd	89 b
1	5	35 ab	61 bc	83 b
21	0 (air)	57 c	78 d	90 b
21	5	43 b	49 b	79 b

[1] Each value is the mean of 6 tests with 50 fruit examined for each atmosphere, each removal period, and each test. Values in each column followed by the same letter or letters do not differ significantly at the 5-percent level.

significantly less decay than fruits from other atmospheres. (Data not shown in table.) Even in these atmospheres the fruit decay averaged 80 percent. This would indicate that low O_2 levels or atmospheres with CO_2 had a delaying action on growth of the decay-producing organisms rather than any lethal action.

In these tests, when inoculated peaches were removed from the different controlled atmospheres, they had a high percentage of greenish-brown spots or streaks. The injury was severe on the peaches but nectarines were rarely injured. Since the injury was uniform on peaches from each atmosphere, this injury probably had little influence on decay development. The exact cause of this injury was not determined, but it probably is related to inoculation procedures since the uninoculated peaches were not similarly injured.

Throughout the tests, most of the decay was caused by the brown rot

organism. However, when peaches were ripened after 6 weeks' storage, penicillium decay also became severe. It was more severe on peaches from air than from any other atmosphere, and was far more severe on peaches previously stored for 9 weeks than for 6 weeks. Less decay developed on peaches stored in ¼ percent O_2 than in other atmospheres. Penicillium decay was not severe on peaches previously stored for only 3 weeks, and was not severe on any nectarines, regardless of atmosphere or length of time in storage.

TABLE 15.—*Relation of O_2 and CO_2 levels during storage to subsequent decay of inoculated peaches and nectarines during ripening in air for 4 days at 65° F. (1965 and 1966)* [1]

Percent CO_2 during storage	Decay of fruit from O_2 level of—			CO_2 mean
	¼ percent	1 percent	21 percent	
	Percent	*Percent*	*Percent*	*Percent*
0	38 b	65 c	75 d	59 b
5	28 a	60 c	57 c	48 a
O_2 mean	33 a	63 b	66 b	

[1] Each value in main block (inside heavy line) is the mean of decay developing after 3, 6, and 9 weeks' storage. Values in each block followed by the same letter do not differ significantly at the 5-percent level.

GENERAL DISCUSSION AND CONCLUSIONS

For storage as long as 3 weeks, peaches and nectarines should be held at 32° F. rather than 40°. In this respect, the findings in these tests agree with those of earlier workers.[8] The peach and nectarine varieties used in these tests could be stored at least 3 weeks in air (21 percent O_2–zero CO_2) at 32° without serious deterioration of their quality. Their external appearance remained good during 9 weeks' storage in air (the duration of these tests). However, their internal appearance was greatly affected after 6 weeks' storage, or longer. Modifying the storage atmosphere has certain beneficial effects on the internal appearance of the fruit, as well as on other qualities. These beneficial effects often were not apparent when the fruits were removed from the low temperatures but became apparent during ripening in air at 65°. Peaches and nectarines stored in atmospheres with 1 percent O_2 and 5 percent CO_2 at 32° for 6 or 9 weeks and then ripened in air had better flesh color, texture, and flavor and somewhat less decay than peaches and nectarines stored in air or in 1 percent O_2 and zero CO_2. Most beneficial effects of the controlled atmospheres appeared to be the result of the presence of 5 percent CO_2 (table 16). The beneficial effects from lower O_2 levels were not as readily apparent nor as con-

[8] See footnote 2, page 2.

sistent as were the effects from 5 percent CO_2. Nevertheless, fruit from lower O_2 levels had lower respiration rates, tended to remain firmer during storage, develop less decay, and to be slightly more acid than fruit from the higher O_2 levels. The very low O_2 level ($\frac{1}{4}$ percent) must be ruled out as a storage atmosphere, however, because fruit from this atmosphere sometimes had a winelike or fermented taste.

TABLE 16.—*Quality and metabolic response of peaches and nectarines stored at 32° F., with and without CO_2, and then ripened in air at 65° (1966)* [1]

Attribute measured	Mean values for fruits from CO_2 level of—	
	0 percent	5 percent
Flesh color after ripening——100 indicates excellent color——	82.0 b	96.0 a
Graininess after ripening——100 indicates no graininess——	82.0 b	93.0 a
Firmness at removal——pounds——	9.1 b	9.6 a
Firmness after ripening——do——	2.8 a	1.9 b
CO_2 production in air at 65° after storage——mg./kg./hr.——	59.0 a	55.0 b
Acidity after ripening——mg./100 g.——	530.0 b	582.0 a
Taste rating after ripening 7-like very much, 1-dislike very much——	3.8 b	4.2 a
Decay after ripening——percent——	59.0 a	48.0 b

[1] Paired mean values (except decay) differ from each other at the 1-percent level. Mean values for decay differ at the 5-percent level.

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