CONTROLLED-ATMOSPHERE STORAGE OF STARKING DELICIOUS APPLES IN THE PACIFIC NORTHWEST

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SUMMARY AND CONCLUSIONS

Starking Delicious apples were stored for approximately 9 months in controlled-atmosphere cabinets. The fruit in 2 cabinets, in which oxygen levels of 3.2 and 4.4 percent were maintained, was superior in appearance and texture to similar fruit in a cabinet with 6.2 percent oxygen. The latter fruit was not markedly different in texture and flavor from the check fruit stored for the same period in regular refrigerated air storage. The carbon dioxide concentrations in the 3 cabinets were 0.3 percent and 2.4 percent in the low-oxygen cabinets and 0.4 percent in the cabinet with 6 percent oxygen.

The better appearance and texture of Starking Delicious apples in the best of the C.A. storage lots, compared with the check lots, was accompanied by a loss of varietal flavor. However, the fruit could withstand prolonged exposure at room temperature (shelf life) without developing stale, acetaldehyde flavor.

The fruit showed considerable core and flesh browning in the modified atmosphere lots after a week or more at room temperature.

Activated carbon was effective as an air purification agent throughout the season and minimized box odors and off-flavors caused by box odors. Its use in controlled-atmosphere storage appears justified on this basis.

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The atmosphere in controlled-atmosphere storage is characterized by lower oxygen and higher carbon dioxide concentrations than normal air, which contains about 21 percent oxygen and 0.03 percent carbon dioxide. Controlled-atmosphere (C.A.) storage has been used commercially in England for many years and is being used increasingly in New England and New York. The total C.A. storage capacity in the East is approximately 700,000 boxes, according to Smock (10).[1]

In England and in the Eastern United States, such storage is used for varieties of apples that cannot be stored long at 31° without developing flesh browning or other disorders. In New York and New England, McIntosh is the principal variety held in controlled atmospheres. McIntosh apples may develop serious brown core during long storage at 31°. By the maintenance of a proper storage atmosphere and a temperature of 38°, brown core is prevented and the storage life of the fruit lengthened. In addition, the market shelf life of fruit after removal from controlled-atmosphere storage may be several times as long as that of fruit from regular storage.

No C.A. storages for apples have been constructed in the Pacific Northwest, probably because the principal varieties grown there are tolerant of 31° F. storage and may be held for long periods at that temperature. However, Smock (10) recently reported benefits from controlled-atmosphere storage to a number of varieties, including Golden Delicious and Delicious, grown in New York and Washington. Smock recommended controlled-atmospheres containing about 3 percent oxygen and 2 to 3 percent carbon dioxide, but Fisher (3) found that 2.5 percent oxygen without any carbon dioxide was the best atmosphere for storing Delicious apples, and that 5 percent carbon dioxide hastened the onset of mealiness.

The Delicious variety constitutes about 60 percent of the total Washington apple production. Extensive new plantings, mostly red strains of Delicious, will further increase the preponderance of this variety. Consequently, all possibilities for lengthening the storage life and providing better quality fruit late in the season merit special attention. Controlled-atmosphere storage offers such possibilities.

The autumn movement of Delicious apples from the Pacific Northwest has been reduced in recent years by the increased production in the East of high quality fruit, which enjoys a low-cost transportation advantage in that area.

During the 1953-54 storage season tests were run to determine the effect of C.A. storage on the quality of Starking Delicious and Golden Delicious apples grown in the area of Wenatchee, Wash. Experimental lots of these varieties were held at approximately 31° F. with three different controlled atmospheres.

The objectives of this experiment were as follows:

1. To determine the increase in storage life when Starking Delicious apples grown in the Pacific Northwest were stored in C.A. storage.

2. To compare the dessert quality of C.A. stored apples with that of fruit from normal air storage.

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[1] Underscored figures in parentheses refer to Literature Cited, page 15.

3. To study the response of fruit held for 1 month at 70° F. after being removed from C.A. storage and fruit held for 1 month at 31° and a week at 70° after being removed from C.A. storage.

4. To compare the condition of fruit stored at 3 percent oxygen and no carbon dioxide with that stored at 3 percent oxygen and 2 to 3 percent carbon dioxide.

5. To permit commercial shippers of apples from the district to compare the fruit from C.A. storage and from normal air storage.

6. To evaluate the effectiveness of activated coconut-shell carbon air purification for minimizing odors in C.A. storage.

PROCEDURE

Controlled-Atmosphere Cabinets and Their Operation

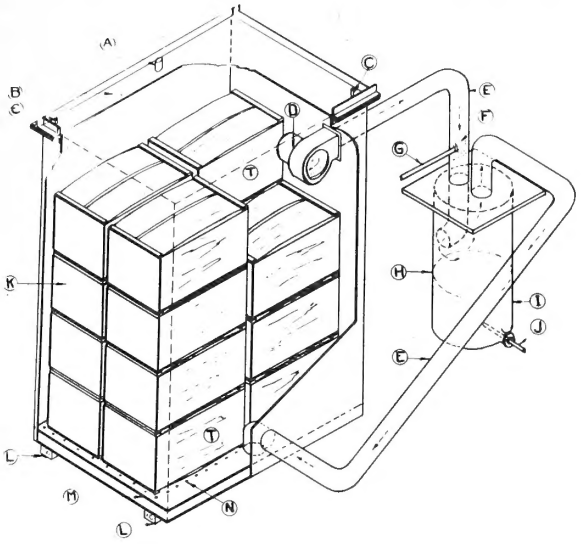
The controlled atmospheres were maintained in 3 sheet-metal cabinets, each having a volume of approximately 45 cubic feet. The structure of the cabinets and arrangement of their loading pattern are illustrated in figure 1. The lids were bolted down after the cabinets were loaded with fruit. Fifty c. f. m. of air was circulated by the fan from the top of each cabinet, past the spray nozzle, and discharged tangentially in the glass scrubber chamber to separate the spray droplets from the air stream. The air left the scrubber chamber through the top center opening and passed through the duct to the plenum space beneath the false floor in the storage cabinet. Quarter-inch holes in the false floor allowed the air to be distributed uniformly in the spaces between the box stacks. In one cabinet (no. 3), the air at the fan inlet was drawn through an activated carbon filter of the cannister type. Air ducts were made of 3-inch polyethylene tubing.

Undesired carbon dioxide was removed by passing the air through a caustic spray as it entered the scrubber chamber. Pyrogallol was added to the caustic solution when it was desired to remove both carbon dioxide and oxygen. The solution was circulated by an all-iron gear-type pump, which had a capacity of 1 gallon per minute against a 10-foot head. Individual pumps were provided for each cabinet, but the 3 pumps were mounted on a common stand and belt-driven by a single 1/4-hp. motor. Quantities of spray were varied with a bypass around the spray nozzle of each cabinet. The caustic solution was circulated in 3/4-inch polyethylene tubing.

The caustic solution used in these tests was potassium hydroxide, to eliminate the difficulties with the carbonate precipitate encountered with sodium hydroxide. Two of the cabinets developed serious air leaks. In the cabinet having the least leakage, pyrogallol was entirely effective in compensating for the leakage. In the cabinet with the greater leakage, however, control was more difficult, and it was not possible to maintain the oxygen concentration as low as originally intended. Carbon dioxide and oxygen concentrations were measured intermittently with an Orsat gas analyzer.

Fruit and air temperatures in each cabinet were read at intervals from a hand-balanced semiprecision potentiometer operated in conjunction with copper-constantan thermocouples placed in and near the boxes marked "T" in figure 1. The cabinets were located in a refrigerated storage room. No refrigeration apparatus was placed within the cabinets. The refrigerated room was kept slightly cooler than the 31° temperature desired in the cabinets to compensate for the respiratory heat of the fruit and heat input from the fans and pumps. The average temperatures for each cabinet for the storage season are listed in table 1.

Just before the cabinets were opened, an air sample was drawn from each one and analyzed for ethylene and nonethylenic volatiles by the method described by Gerhardt (4).



AMS NEG. 3965-57(3)

Figure 1.--Diagram of controlled-atmosphere cabinet and scrubber

A. Opening for thermocouple leads. Similar opening on opposite side for power wiring.
B. Removable cover with angle iron reinforcing around edges.
C. Air vent.
D. Circulation fan bolted to side of cabinet.
E. 3-inch diameter air duct.
F. Spray nozzle in air duct.
G. Caustic solution line from pump (bypass not shown).
H. Caustic solution level.
I. 10-inch diameter x 18-inch glass scrubber chamber.
J. Caustic solution line to pump.
K. 15 boxes of test fruit.
L. Spacer strips to provide space between cabinet and storage room floor.
M. Plywood floor spaced 2 inches above bottom to provide supply air plenum.
N. 1/4-inch supply air openings from plenum arranged 3 inches on centers on outside of stacks and between stacks.
T. Boxes containing thermocouples.

Fruit Handling and Methods of Analysis

The experimental fruit was grown at the Washington State College Tree Fruit Experiment Station, at Wenatchee. The Starking Delicious apples were picked on October 2, 1953, and the Golden Delicious on October 20. After harvest, the fruit was immediately placed at 31° F., where it was hand-sorted, sized, and composited.[2] The fruit was packed in standard Northwest wooden apple boxes. Half of the apples in the boxes were wrapped in oiled paper, and the rest were packed without wraps. All boxes were lidded for ease of handling.

The fruit remained in regular storage at 31° F. until November 3, when 7 boxes of Golden Delicious and 8 boxes of Starking Delicious were placed in each of 3 sheet-metal

[2] In this report, "composited" means the making of a composite sample by taking fruit from each of a number of boxes of fruit and putting it into a single box.

Table 1.--Oxygen and carbon dioxide concentrations and temperatures in controlled-atmosphere cabinets

Cabinet no.	Proposed concentration[1]		Average concentration for storage season		Average temperature during storage season
	Oxygen	Carbon dioxide	Oxygen	Carbon dioxide	
	Percent	*Percent*	*Percent*	*Percent*	°*F.*
1	3	2-3	4.4	2.4	30.6
2	3	0	3.2	.3	29.7
3[2]	3	0	6.2	.4	31.0

[1] Approximate concentration.
[2] Equipped with cannister containing 1.5 pounds of activated coconut-shell carbon.

cabinets for C.A. storage. Two boxes of each variety were placed in each of 3 layers, and 1 box of Golden Delicious and 2 of Starking Delicious were placed in the fourth, or top, layer.

In accordance with Smock's recommendation, the first cabinet was to contain an atmosphere of about 3 percent oxygen and 2 to 3 percent carbon dioxide. The other two cabinets were to contain atmospheres of approximately 3 percent oxygen and no carbon dioxide, in accordance with Fisher's recommendation. One of the latter cabinets was equipped with an activated carbon-adsorption unit.

The oxygen and carbon dioxide levels in the cabinets were obtained through the normal respiration of the fruit. Excess carbon dioxide was absorbed in a potassium hydroxide solution; and if the oxygen fell below a concentration of 3 percent, a small amount of air was allowed to enter the cabinet. Because of leakages in the cabinets and the aerating system, the proposed gas concentrations were not rigidly maintained (table 1).

Apples of both varieties were held at 31° F. in regular-air storage for comparison with the fruit from the C.A. cabinets; the fruit in regular-air storage was evaluated at intervals by the indices described later. The fruit in C.A. storage was similarly evaluated at the end of the season. By this procedure, the retardation of ripening due to controlled atmospheres could be evaluated by pairing the quality of the C.A. fruit with fruit withdrawn from regular-air storage.

The following physical and chemical determinations were made on sample lots of 20 fruits:

1) Firmness--Magness-Taylor Pressure Tester with 7/16-inch plunger

2) Soluble pectins--Modified Carré-Haynes Method (1)

3) Total acidity as malic acid--Titration

4) Hydrogen-ion concentration--Beckman pH Meter

5) Soluble solids--Refractometer

6) Reducing sugar
7) Total sugars
} --Sumner Method (11)

Sampling Schedule

Initial determinations were made on all lots November 3; later tests were made on fruit from regular-air storage (check fruit) on April 1, May 10, and June 4, 1954. On July 27, tests were made on both the C. A. fruit and the check fruit, and fruit was selected from each lot for respiratory studies. The respiration rates were determined by measuring at intervals the carbon dioxide evolved during 3 weeks at 70° F.

On each of these dates, except November 3, fruits from the sampled lots were placed in the ripening room at 70° F., and after 1 to 2 weeks, firmness, total acidity, pH, and soluble solids were determined.

On August 4, 5, and 6, samples of fruit from regular storage and from the C. A. cabinets were displayed at the laboratory, and interested fruit shippers and growers were invited to examine and score them. Samples included fruit that had been held at 31° F. and at 70° since removal from the cabinets. Thirty-four score sheets were received and analyzed.

Data on scald, decay, and breakdown after C. A. storage were obtained from samples from each lot held for 1 month at 70° F. and from samples held for 1 month in regular storage at 31° followed by 8 days at 70°.

RESULTS

At the start of the C. A. tests the Golden Delicious apples were more mature than desired. Subsequent behavior in regular storage and negligible effects from C. A. storage indicated this fruit was too mature to respond appreciably to the controlled atmospheres. Consequently, data on Golden Delicious apples are not included in this report. Additional tests will be run on this variety.

Odors and Volatile Concentrations

When cabinets 1 and 2 were opened, there was a strong pine-box odor; but in cabinet 3, which had a cannister containing 1.5 pounds of activated carbon, there was little odor of any kind. In none of the cabinets was there an apple odor. If an apple odor were present, the box odor in cabinets 1 and 2 masked it. Corresponding box flavors were likewise detected in the apples from cabinets 1 and 2.

Measurements of the volatile concentration of the air in the cabinets substantiated the odor observations. Analyses of the nonethylenic volatiles gave the following results in terms of $Ce(SO_4)_2$ reduced per cubic foot of air: Cabinet 1, 65.5 mg.; cabinet 2, 110.6 mg.; and cabinet 3, 6.0 mg. Concentrations of volatiles that reduce 2 to 4 mg. of $Ce(SO_4)_2$ per cubic foot of air are considered low, whereas a reduction of approximately 20 mg. $Ce(SO_4)_2$ per cubic foot of air represents a high volatile level (9). It is evident that the volatiles were several times higher in cabinets 1 and 2 than in the most odorous commercial storages, whereas the volatiles were satisfactorily controlled in cabinet 3. This control of volatiles was accomplished without recharging the carbon cannister. In some previous tests (6), apples were stored in the same cabinets in normal air until the end of March. The volatiles rose to a high level in January, and the carbon had to be replaced.

Chemical, Physical, and Organoleptic Evaluations

On June 4, after 7 months in regular-air storage at 31° F., the Starking Delicious fruit was still attractive. The texture was crisp and the flavor mild. Slight staleness was detected in a few fruits (table 2). On July 27, the fruit from regular-air storage was judged to have better varietal flavor than that from any of the C. A. cabinets. All of the apples in the controlled atmospheres had lost much of their varietal flavor, which was never fully regained with subsequent holding (table 3).

Table 2.--Organoleptic evaluation and physical and chemical determinations for Starking Delicious apples at picking and after storage for various periods in regular 31° F. storage

Date sampled	Period stored at--		Firmness	Soluble pectin	Total acidity (malic acid)	pH	Soluble solids	Sugars		Remarks
	31° F.	70° F.						Total	Reducing	
	Days	*Days*	*Pounds*	*Percent*	*Percent*		*Percent*	*Percent*	*Percent*	
1953 Nov. 3.....	32	0	17.4	0.049	0.204	4.10	12.2	12.80	9.40	Picked at good maturity for storage--well colored
1954 Apr. 1.....	180	0	15.0	.082	.123	4.43	12.6	12.20	10.68	Attractive, crisp--flavor good
Apr. 16....	180	15	12.0	--	.099	4.42	--	--	--	Yielding to mealy--flavor fair--none stale
May 10.....	219	0	13.5	--	.090	4.46	11.8	--	10.92	Attractive, crisp--flavor mild
May 18.....	219	8	12.0	--	.102	4.30	12.5	--	--	Yielding to mealy--flavor fair--none stale
June 4.....	244	0	13.5	.077	.107	4.38	13.4	12.40	12.00	Attractive, crisp--flavor mild to slightly stale
June 11....	244	7	12.1	.080	.083	4.52	13.0	--	--	Yielding--somewhat overripe--flavor fair to slightly stale

Table 3.--Organoleptic evaluation and physical and chemical determinations for Starking Delicious apples removed from regular and controlled-atmosphere storage, July 27, 1954

Cabinet no.	Firmness[1]	Soluble pectin	Total acidity (malic acid)	pH	Soluble	Sugars		Remarks
						Total	Reducing	
	Pounds	*Percent*	*Percent*		*Percent*	*Percent*	*Percent*	
1[2].....	13.60	0.087	0.169	4.30	13.0	12.80	11.92	Box flavor--acid
2[2].....	14.00	.082	.174	4.35	13.2	12.80	11.32	No varietal flavor--acid
3[2].....	11.90	.090	.130	4.45	12.5	12.80	11.60	No varietal flavor--acid
Check[2].....	11.77	.086	.099	4.70	12.4	12.24	11.92	Best of the 4--has most varietal flavor
1[3].....	10.90	.082	.142	4.35	13.8	12.64	11.72	Slight off-flavor--little varietal flavor
2[3].....	12.10	.075	.137	4.38	13.4	12.24	11.44	Little varietal flavor
3[3].....	11.87	.080	.110	4.50	13.4	12.16	11.52	Little varietal flavor
Check[3].....	11.37	.081	.059	4.99	12.0	11.44	10.20	Stale--but has varietal flavor

[1] L.S.D. at the 5 percent level = 0.75 pound.
[2] Sampled July 27, 1954, upon removal from cold storage. Check fruit was stored at 31° F. in regular-air storage.
[3] Sampled August 3, 1954, after holding 7 days at 70° F.

The fruit from the cabinets was distinctly sour tasting, and the chemical tests showed it was markedly more acid than fruit from regular-air storage. Total acids in the fruit at the time it was removed from the 3 cabinets averaged 0.158 percent, whereas fruit from regular-air storage at a comparable time had 0.099 percent. A comparison of total acidity changes in fruit in regular-air and C.A. storage is shown in figure 2.

Hydrogen-ion concentration followed the same trend as total acidity. The fruit from cabinets 1 and 2 was crisp, whereas that from cabinet 3 and from air storage was softer and varied from crisp to yielding. Pressure-test readings of these 4 lots were 13.6, 14.0, 11.9, and 11.8 pounds, respectively. Figure 3 shows the changes in firmness of the fruit (fruit in regular-air storage) as the storage season progressed and the firmness of the C.A. lots at the end of the storage period. No marked differences in soluble pectin, soluble solids, or sugars, were found among the 4 lots.

After 1 week at 70° F., the fruit from regular-air storage had declined in quality and was mostly mealy to yielding in texture and mild to stale in flavor, although it still retained varietal flavor. The C.A. fruit had lost most of the box flavor but was still acid and lacked varietal flavor. It was superior in texture to the fruit from regular-air storage, and no staleness was detected. Firmness and total acidity had declined in all lots, but their relation between lots was about the same as it had been the previous week. No marked changes in composition of the fruit were detected by other analytical tests.

The controlled atmosphere had retarded the respiratory rate of the fruit as shown in figure 4. The respiration studies were made on apples at 70° F. beginning 24 hours after the C.A. cabinets were opened. The 24-hour period allowed the fruits to warm to room temperature and reach an equilibrium with the surrounding air. The respiration studies extended over a 3-week period.

Respiratory values, as indicated by carbon dioxide determinations, reached a peak 24 hours after the measurements were started. At that time the fruit from regular-air storage was respiring at a rate of about 31.5 mg. CO_2 per kg. per hr. and the C.A. fruit 19.0 to 22.0 mg., or about two-thirds as high. The rate of CO_2 production of the fruit from regular-air storage dropped sharply for 2 days and then constantly declined over the remaining 17-day period. The rate for the C.A. fruit likewise declined for 2 days and then remained fairly constant for 6 days, after which the rate increased very slowly. At the end of the 3-week period, the fruit from both types of storage were respiring at about the same rates, the range being 18 to 21 mg. CO_2 per kg. per hr.

Texture and Flavor Evaluation by Taste Panel

Data from the score sheets used by the taste panel are summarized in table 4. Preferences of the panel members followed the same order as their average scores. Therefore, only their scores are presented, together with a summary of comments on flavor and appearance.

Fruit from cabinet 2 received the best texture score, and in most cases that from cabinet 1 received the next best. Fruit from regular-air storage was rated poorest in texture.

A different situation prevailed for flavor. Fruit taken directly from the 31° regular-air storage received the highest score and the greatest number of favorable comments; fruit from cabinet 2 received the lowest flavor score. After 1 week at 70° the fruit from cabinets 1 and 2 was rated higher than the other fruit. By that time the fruit from regular-air storage had deteriorated so much that it was rated lowest in flavor. These results demonstrated some extension of shelf life by controlled-atmosphere storage.

A high proportion of the judges noted off-flavors in the fruit from cabinets 1 and 2 as it came from cold storage. However, when the fruit from these cabinets was held for a week at 70° F., most of the objectionable flavor had disappeared, as indicated by the smaller number of judges reporting off-flavors.

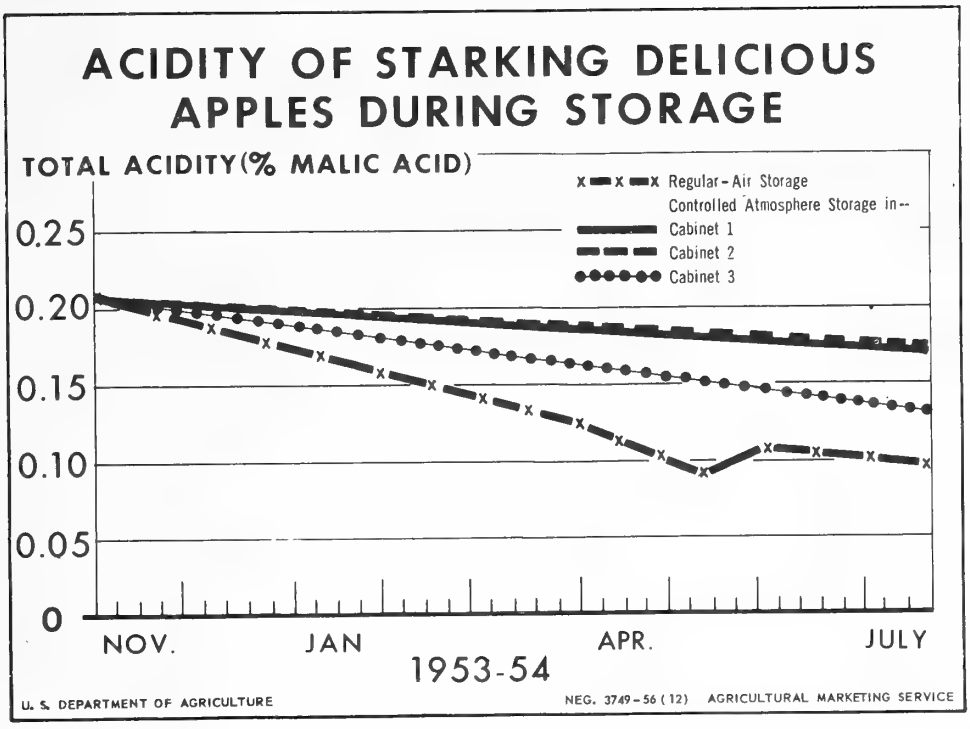


Figure 2

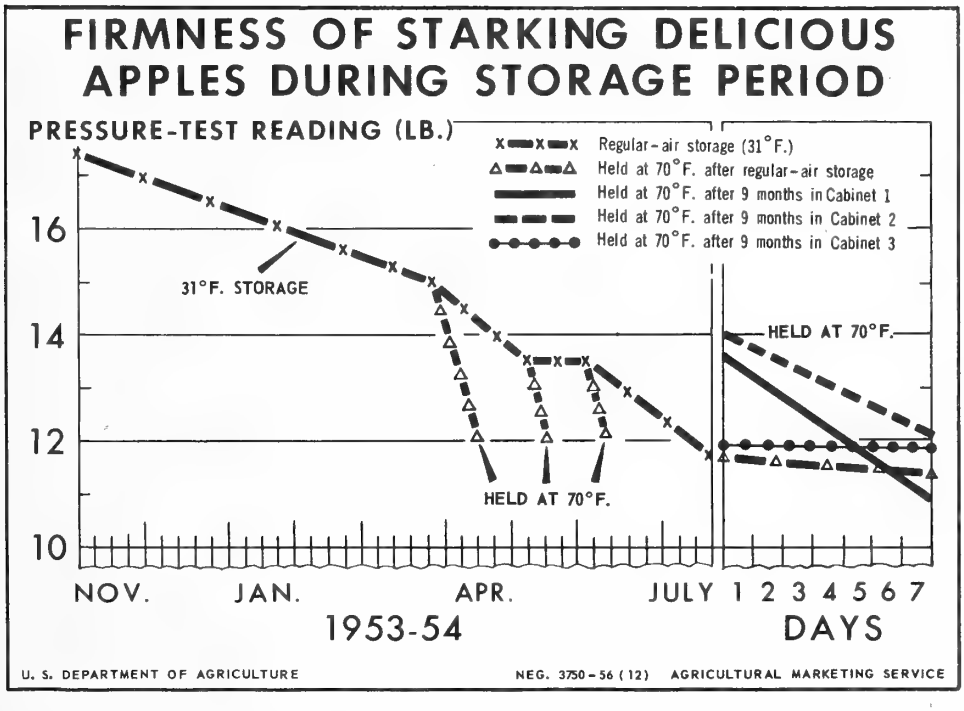


Figure 3

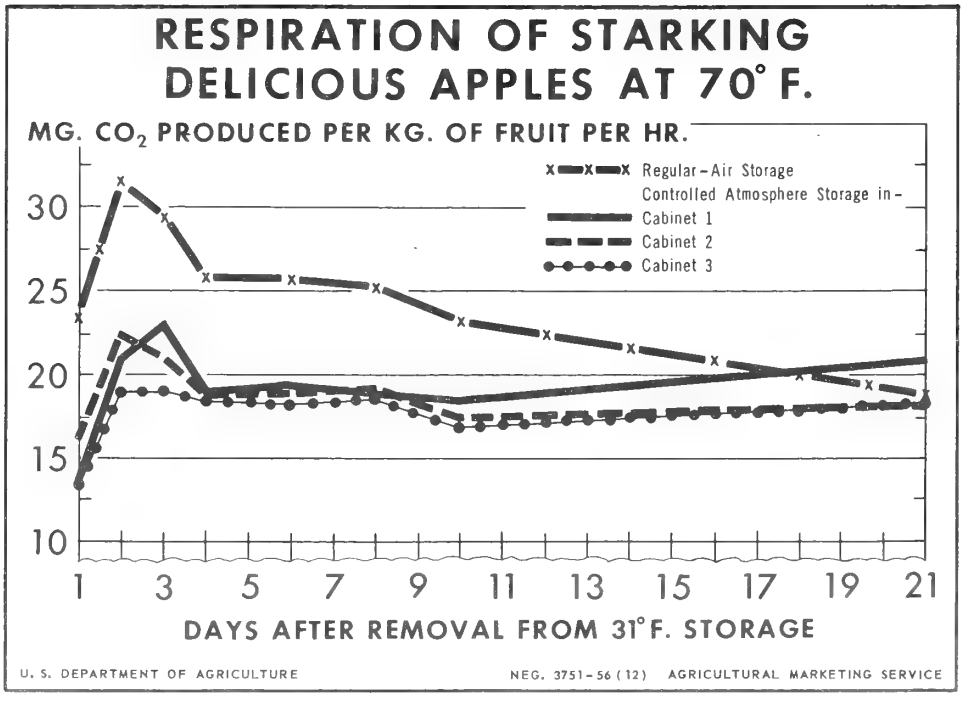

RESPIRATION OF STARKING DELICIOUS APPLES AT 70° F.
MG. CO_2 PRODUCED PER KG. OF FRUIT PER HR.
Regular-Air Storage
Controlled Atmosphere Storage in-
Cabinet 1
Cabinet 2
Cabinet 3
30
25
20
15
10
1
3
5
7
9
11
13
15
17
19
21
DAYS AFTER REMOVAL FROM 31° F. STORAGE
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Figure 4

Table 4.--Judges' evaluation of texture, flavor, and appearance of cold and ripened Starking Delicious apples, 1 week after removal from the various storage atmospheres

Lot and cabinet no.	Average texture score[1]	Average flavor score[2]	Number of judges who made comments on--				
			Flavor			Scald	Good appearance
			Good to fair	Off	None or flat		
From 31°:							
1[3].....	3.3	3.1	2	7	9	1	1
2[3].....	3.5	2.7	1	12	9	1	1
3[3].....	3.0	3.2	--	4	9	--	2
Check[4].....	2.6	3.3	8	2	9	--	--
From 70°:							
1[5].....	2.2	3.3	1	3	14	--	3
2[5].....	2.5	3.3	2	--	13	--	3
3[5].....	2.3	3.0	2	--	9	--	2
Check[5].....	1.7	2.7	4	2	6	--	--

[1] Texture scores: 1, Mealy; 2, yielding; 3, crisp; 4, firm; 5, hard.
[2] Flavor scores: 1, Stale; 2, off-flavor; 3, acid or sour; 4, mild; 5, full-flavor.
[3] Stored at 31° F. after removal from modified atmospheres on July 27, 1954, until judging on Aug. 4, 5, and 6.
[4] From regular-air storage at 31°F.
[5] Stored at 70° F. from July 27, 1954, until judging on Aug. 4, 5, and 6.

This reaction generally substantiates the recommendation that fruit from controlled-atmosphere storage be withheld from retail channels for the period immediately after removal from the modified atmosphere so that off-flavors have time to disappear.

Disorders After Removal From Controlled-Atmosphere Storage

Fruit held after removal from C.A. storage for a month at 70° F., or for a month at 31° plus a week at 70°, was examined for scald, breakdown, decay, and core browning (table 5).

Oil wraps retarded scald development under all storage conditions. There was no relation between composition of the storage atmosphere and scald development.

Most decay was observed in apples from cabinet 3; ripeness was also more advanced in these apples than in those in cabinets 1 and 2. The percentage of breakdown could not be related to atmospheric differences.

A faint core and flesh browning was found in all lots. In fruit held for a month at 70° F., the disorder affected from 31.1 to 46.3 percent of the fruit from cabinets 1 and 2 and from 11.8 to 18.7 percent of the fruit in cabinet 3. The check fruit had about the same amount of browning as that in cabinet 3.

In fruit from controlled atmospheres held in regular-air storage at 31° for an additional month and then for a week at 70°, 36.4 to 42.0 percent of the apples developed flesh browning. This disorder was negligible in the fruit stored throughout the season in normal air.

Table 5.--Prevalence of various disorders in Starking Delicious apples from controlled-atmosphere cabinets and from regular storage after prolonged holding in normal atmospheres

Cabinet No.	Wrap used on fruit	Scald	Breakdown	Core and flesh browning	Decay
		After 1 month at 70° F.			
		Percent	*Percent*	*Percent*	*Percent*
1	None	22.6	10.7	45.3	12.8
	Oil paper	8.1	5.4	31.1	7.6
2	None	32.9	8.9	46.3	13.3
	Oil paper	12.7	12.4	45.0	7.4
3	None	17.3	8.5	18.7	31.7
	Oil paper	14.5	6.2	11.8	23.5
Check[1]	None	34.3	4.1	18.6	4.1
	Oil paper	11.5	1.9	12.5	9.4
	After 1 month at 31° F., 1 week at 70° F.				
1	None	28.1	8.0	42.0	8.0
2	None	9.3	2.6	37.4	1.3
3	Oil paper	4.5	4.3	36.4	19.8
Check [1]	Oil paper	5.7	1.4	1.4	1.4

[1] Regular-air storage.

The apples from the controlled-atmosphere cabinets ripened and became mealy without developing the staleness characterized by acetaldehyde, which generally accompanies mealiness in air-stored fruit.

DISCUSSION

The results show clearly that fruit stored in controlled atmosphere was firmer and had a better texture than fruit stored in regular air. However, controlled-atmosphere storage caused loss of varietal flavor. Even after the fruit had been held a week to free it from off-flavors, it did not have the flavor characteristic of the variety.

This effect on the condition and flavor of apples raises a problem for commercial users of controlled-atmosphere storage. These users may find that the fruit they are trying to sell is in better condition than fruit from regular storage, but that their fruit lacks flavor appeal. Although appearance and texture are probably the most important factors in sales at the wholesale level, they may be less important at the retail level. Poor flavor or lack of flavor might influence the consumer against repeat purchasing. Information on this aspect of the problem is beyond the scope of this investigation, but it must be noted that any large-scale operation of controlled-atmosphere storage for Starking Delicious apples would involve the hazard of merchandising fruit lacking true Delicious flavor. It is possible, however, that since controlled-atmosphere fruit withstands prolonged exposure to room temperatures without developing stale acetaldehyde flavor, such fruit would appeal to customers and counteract sales resistance engendered by lack of varietal flavor.

Fruit from cabinet 1, with low oxygen and 2.4 percent carbon dioxide, and that from cabinet 2, with low oxygen and only a trace of carbon dioxide, differed little in texture and flavor. Carbon dioxide at these low concentrations apparently has little influence on the fruit, the beneficial effect of the controlled-atmosphere storage being largely due to the low oxygen. Fisher (3) reported that 5 percent carbon dioxide hastens the development of mealiness. Apparently 2.4 percent is below the concentration which produces this effect.

The experience with the experimental cabinets demonstrates the importance of eliminating air leakage in controlled-atmosphere storage. In cabinet 3 where leakage was excessive, it was impossible to attain the desired low level of oxygen. An oxygen concentration of approximately 6 percent instead of the desired 3 percent was sufficient to eliminate most of the benefit attributable to controlled-atmosphere storage.

Some insight into the degree of tightness of storage chambers can be gained by considering the amount of air leakage allowable to supply the oxygen requirements of the fruit in the cabinet. Cabinet 2 contained approximately 300 pounds of Starking Delicious and 265 pounds of Golden Delicious apples. If it is assumed that carbon dioxide production and oxygen consumption are about half of that in normal air storage, approximately 1.5 mg. of carbon dioxide per kg. of fruit per hour is produced and an equal amount of oxygen is consumed. Therefore, the fruit in the cabinet requires 9,220 mg. of oxygen per 24 hours. This requirement is satisfied by air leakage of 1.34 cu. ft. per 24 hours when an oxygen concentration of 2.75 percent exists in the cabinet. When this air leakage value is expressed as air changes per day with respect to gross cabinet volume, it amounts to 0.03 air changes per day. Measurements of air-change rates for commercial storages showed that air changed once or twice a day in relatively tight rooms and up to 10 times a day in other rooms (9).

It was observed that the worst leaks occurred following occasional periods of higher than normal temperatures in the cabinets, caused by refrigeration control failure. Pflug and Dewey (7) and Pflug and Southwick (8) called attention to the important part temperature fluctuation plays in the leakage from controlled-atmosphere storage, and the experience with the metal cabinets is in line with their conclusions.

The ability of the carbon-purification cannister in cabinet 3 to remain operative for the entire season was a surprise; its efficiency probably was due to a diminution in the volatile producing characteristics of the fruit stored under modified atmosphere. Fidler (2) reported that fruit stored in modified atmospheres produces nonethylenic volatiles at a lower rate than similar fruit stored in air at the same temperature. Confirmation of this point is shown by the following calculations: If the fruit produced volatiles at a rate comparable to that observed in air storage early in the storage season, as reported by Gerhardt (5), volatiles equivalent to approximately 1,200 mg. of $Ce(SO_4)_2$ reduced would be produced daily. Air leakage to balance this production and maintain the observed volatile concentration in cabinet 2 would be 10.8 cu. ft. per day. The great difference between air leakage to balance oxygen requirements (1.34 cu. ft. per day) and that to balance the calculated volatile production indicates a reduction in rate of volatile production similar to that observed by Fidler.

The concentration of odors from the wooden boxes constituted such a serious factor in the cabinets without carbon that an off-flavor was carried by the fruit for some time after its removal from C.A. storage. In keeping box odors and off-flavors from this source at a minimum, air purification can perform an important and necessary function in C.A. storage. On the basis of this experience, the writers recommend its use in such storages and, for further experimental work, have equipped the other two cabinets with carbon filters.

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