ARTICLE 39-73
MAY 1957

PROGRESS REPORT ON THE CONTROLLED-ATMOSPHERE STORAGE OF JONATHAN APPLES

By D. H. DEWEY, W. E. BALLINGER and I. J. PFLUG
DEPARTMENTS OF HORTICULTURE AND AGRICULTURAL ENGINEERING

JONATHAN IS THE MOST IMPORTANT variety of apples grown in Michigan. Although widely accepted as an all-purpose apple, it has a relatively short marketing season since its storage life is limited to 3 or 4 months.

Storage at 32° F., which often extends the season for Jonathan apples to early February, is hazardous since the fruit is susceptible to soft scald (Fig. 2). This physiological disorder develops less readily at 36° F. than at 32°; however, another disorder, Jonathan spot (Fig. 1), may cause serious damage at the higher temperature. Jonathan spot becomes more widespread as the storage season progresses, so that the apples must be periodically inspected and moved into market channels before excessive damage occurs.

Controlled-atmosphere storage should be useful in prolonging the storage life of Jonathan apples; however, its suitability to this variety has not been clearly established.

Smock (1949) found that Jonathan apples grown in New York were damaged by carbon dioxide in controlled-atmosphere storage; whereas Plagge (1942) found that this variety in Iowa could be stored in a high level of carbon dioxide without injury. Plagge and Fisher (1942) reported that Jonathan spot was controlled and ripening was delayed by this type of storage.

In other countries, workers—for example, Van Heile (1951) in the Netherlands, Vickery, et al. (1951) and Hall (1955) in Australia, Rasmussen (1951) in Denmark, and Phillips and Poapst (1952) and Fisher (1954) in Canada—report varying degrees of success in controlling Jonathan spot and prolonging the storage and market life of Jonathan apples by controlled-atmosphere storage.

Reprinted from the QUARTERLY BULLETIN of the Michigan Agricultural Experiment Station, Michigan State University, East Lansing. Vol. 39, No. 4, pages 691 to 700. May 1957.

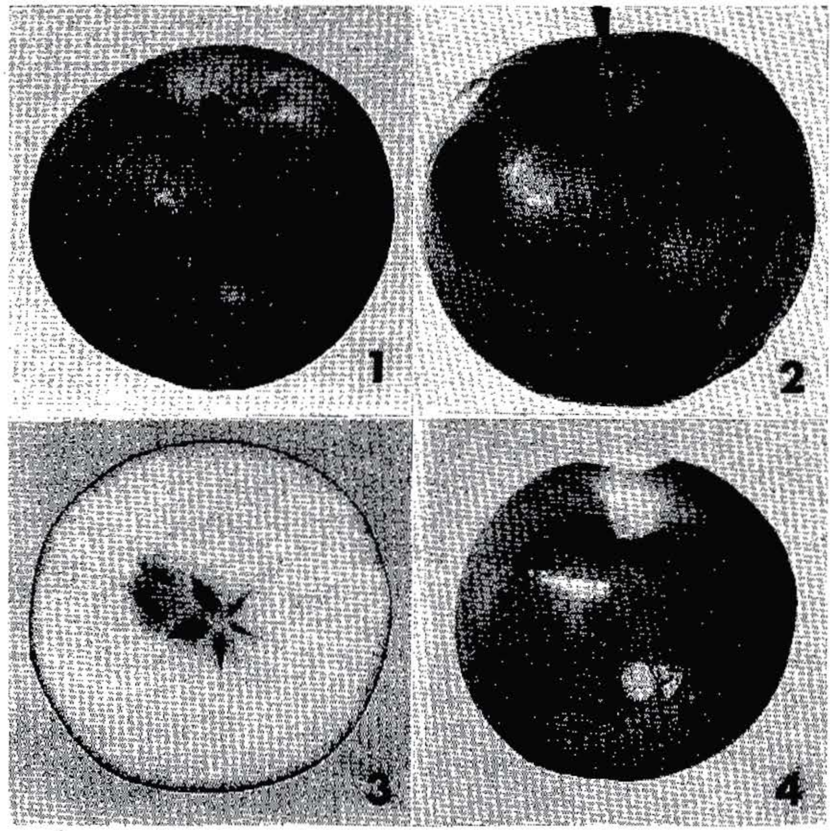

Fig. 1. Jonathan spot on Jonathan apple. The spots are brown and usually confined to the skin. Fig. 2. Soft scald (or ribbon scald) on Jonathan apple. The affected brownish and slightly sunken areas may extend through the skin and into the flesh. Fig. 3. Section of Jonathan apple showing internal or flesh injury caused by carbon dioxide. The cavities or voids in the flesh near the core are surrounded by dry, pithy and brown tissue. Fig. 4. External or surface injury caused by carbon dioxide and characterized by change of skin color from red to reddish-blue or brown.

The findings of Brooks and Harley (1934) indicate that short exposures of Jonathan apples to atmospheres containing relatively high concentrations of carbon dioxide (20 to 25 percent) before storage at 32° F. will reduce or prevent the development of soft scald.

In 1954, experiments were begun to study the response of Michigan-grown Jonathan apples to various concentrations of carbon dioxide and oxygen at several temperatures. Controlled atmospheres were evaluated as a means of maintaining quality for a longer period of time than is possible with regular cold storage.

METHODS AND MATERIALS

Apples harvested October 6, 1954, from the university orchards, and September 29, 1955, from a commercial orchard near Almont, Michigan, were sorted and randomly separated into bushel lots. The fruit was of mixed sizes in 1954, but it was separated into diameter sizes of 2¼ to 2½ inches and 2½ inches and larger in 1955. Two bushels of fruit were stored in closed metal drums in which the atmospheres were adjusted to the desired levels of carbon dioxide and oxygen by ventilation with nitrogen gas and air.

The apples were stored at temperatures of 32°, 36° and 40° F. during the 1954-55 storage season and at 32° and 36° F. during 1955-56. For the 1955-56 storage season, 38 bushels were also stored in each of three pilot-sized chambers in which the atmospheres were maintained by absorbing the excess carbon dioxide with sodium hydroxide, and by ventilating with air to add oxygen. The atmospheres and temperatures used were 7 percent carbon dioxide—14 percent oxygen at 32° to 34° F., and 5 percent carbon dioxide—3 percent oxygen at 32° to 34° and 36° F. In addition, control lots were stored in open crates and within folded polyethylene crate liners in regular storage at 32° F.

Fruit examinations at the end of the storage periods included measurements of flesh firmness by a Taylor-Magness pressure tester, and counts of fruit with external injuries, internal injuries, internal breakdown, soft scald and Jonathan spot.

RESULTS

Eating Quality

1954-55: Apples stored in controlled atmospheres at 32° and 36° F. retained excellent condition and quality to the end of the storage period on May 2 (about 7 months). This was particularly true for apples stored at 32° F. in either 2.5 percent or 5 percent carbon dioxide with 3 percent oxygen, at 36° F. in 7 percent carbon dioxide with 14 percent oxygen, and in 5 percent carbon dioxide with 3 percent oxygen. These apples were practically free of mealiness and retained good flesh texture and flavor for 10 days at room temperature after removal from storage.

Fruit stored at 32° and 36° F. in normal air showed excessive loss of quality at 5½ months. Apples stored at 40° F. for this same period of time depreciated considerably in quality, regardless of the atmosphere employed. Many fruits showed mealiness and internal breakdown and had developed an old flavor, either upon removal from storage or after 10 days at room temperature.

1955-56: Results of experiments using sealed 2-bushel chambers are listed in Table 1.

TABLE 1—Properties of Jonathan apples stored 7 months in regular storage and controlled atmospheres: 1955-56 (averages for 2 bushels of apples)

Atmosphere	Normal air	5% CO_2 3% O_2	2.5% CO_2 3% O_2	7% CO_2 14% O_2	11% CO_2 10% O_2	5% CO_2 16% O_2
Temperature	32° F.					
Properties						
Flesh firmness						
(pressure, lb.)	12.8	14.8	14.4	14.1	14.4	14.3
Loss in pressure (lb.)	7.1	5.1	5.5	5.8	5.5	5.6
Jonathan spot (%)	60.9	0.3	2.2	0.0	0.0	0.4
Soft scald (%)	0.0	0.0	0.0	0.0	0.0	0.0
Internal breakdown (%)	6.2	0.0	0.0	2.5	1.9	2.8
Carbon dioxide injury						
Surface (%)	0.0	0.0	0.0	3.3	0.0	7.2
Flesh (%)	0.0	0.7	0.0	0.0	1.0	0.0
Core browning (%)	0.0	8.6	5.0	22.1	48.6	17.9
Temperature	36° F.					
Properties						
Flesh firmness						
(pressure, lb.)	13.0	14.8	13.5	12.9	14.8	13.2
Loss in pressure (lb.)	6.9	5.1	6.4	7.0	5.1	6.7
Jonathan spot (%)	46.9	0.0	0.0	0.0	0.0	0.0
Soft scald (%)	0.0	0.0	0.0	0.0	0.0	0.0
Internal breakdown (%)	6.4	0.0	0.0	6.0	3.2	6.8
Carbon dioxide injury						
Surface (%)	0.0	0.0	0.0	12.2	10.5	10.9
Flesh (%)	0.0	1.5	0.7	5.0	1.5	0.0
Core browning (%)	0.0	3.6	4.3	3.1	21.4	0.7

The best retention of quality for 7 months of storage was attained with 2.5 or 5 percent carbon dioxide in combination with 3 percent oxygen. The fruit under these conditions was firm and free of internal breakdown. The smaller apples (2¼ to 2½ inches in diameter) showed a slight amount of internal breakdown after holding for 2 weeks at room temperature; this breakdown was the least widespread in the apples that were stored in 5 percent carbon dioxide with 3 percent oxygen at 32° F. After these treatments, the market life of fruit 2½ inches or larger in diameter was limited to less than 2 weeks because of the development of excessive breakdown and mealiness.

Following the other treatments, the smaller-sized fruit varied from slightly to seriously mealy after 2 weeks; the large fruit was unmarketable in about 1 week.

Differences in flesh firmness (as determined by pressure tests) were marked at 32° F., with the controlled-atmosphere fruit 1.3 to 2.0 pounds more firm than those from regular air at the end of the storage period on April 27.

Best quality retention for fruit stored in pilot-sized chambers was attained in an atmosphere of 5 percent carbon dioxide and 3 percent oxygen at 32° to 34° F. This is shown in Table 2 by the lowest amount of internal breakdown and the smallest decrease in flesh firmness at the end of the storage period. Storage at 32° F. in regular air was slightly better in retention of flesh firmness than either of the controlled atmospheres at 38° F. The firmest apples (5 percent CO_2 with 3 percent O_2 at 32° to 34° F.) were marketable for 1 to 2 weeks; whereas the others were unmarketable after 1 week due to the development of mealiness and off-flavor.

Although slightly lacking in typical Jonathan flavor upon removal from storage, all fruit in controlled atmospheres was crisp, juicy, and rated as highly acceptable for eating and cooking purposes.

TABLE 2—Properties of Jonathan apples stored 7 months in regular storage and in 38-bushel capacity controlled-atmosphere chambers: 1955-56

Atmosphere	Normal air	5% CO_2 3% O_2	5% CO_2 3% O_2	7% CO_2 14% O_2
Temperature	32° F.	32°—34° F.	38° F.	38° F.
Properties				
Flesh firmness (pressure, lb.)	14.2	15.1	13.7	13.5
Loss in pressure (lb.)	5.7	4.8	6.2	6.4
Jonathan spot (%)	61.3	0.2	0.2	0.0
Soft scald (%)	0.0	0.0	0.0	0.0
Internal breakdown (%)	13.4	1.8	3.5	5.2
Carbon dioxide injury				
Surface (%)	0.0	0.1	0.0	3.3
Flesh (%)	0.0	1.0	10.5	0.5
Core browning (%)	6.0	21.5	6.0	9.0

Jonathan Spot

1954-55: During the 1954-55 storage season, controlled atmospheres proved highly helpful in preventing the development of Jonathan spot. As shown in Table 3, the percentage of fruit developing spot when stored to March 20 in regular air was excessive; little or none was found in atmospheres containing 2.5 percent or greater amounts of carbon dioxide.

1955-56: Fruit stored in normal air at 32° and 36° F. showed 60.9 and 46.9 percent, respectively, of the fruit to be affected by Jonathan spot at the time of removal from the storage chambers on April 27 (see Table 1). A slight amount of Jonathan spot was evident on the fruit in controlled atmospheres at 32° F. However, it was

TABLE 3—Percentage of Jonathan apples developing Jonathan spot, soft scald and carbon dioxide injury: 1954-55 (averages for 2 bushels of apples)

Treatment		Temperature and date of examination				
Storage atmosphere		40° F.	36° F.		32° F.	
Carbon dioxide	Oxygen	March 20	March 20	May 2	March 20	May 2
			Jonathan Spot			
0.5	3.0	7	6	26	1	28
2.5	3.0	0	1	1	0	3
5.0	3.0	5	1	1	0	0
7.0	14.0	0	0	0	0	0
Normal air		30	35	†	18	†
			Soft Scald			
0.5	3.0	0	0	0	0	0
2.5	3.0	0	0	0	0‡	0‡
5.0	3.0	0	0	0	0	0
7.0	14.0	0	0	0	0	0
Normal air		0	0	†	52	†
			Carbon Dioxide Injury			
0.5	3.0	0	0	0	0	0
2.5	3.0	33*	0	0	0	0
5.0	3.0	17*	5*	8*	0	0
7.0	14.0	12*	0	0	0	8§
Normal air		0	0	†	0	†

*Flesh injury mostly at core area.
†Fruit discarded following March 20 examination.
‡Some fruit used for respiration studies developed soft scald (see page 697).
§Mostly discoloration of skin.

of minor extent and may have been present at the time of placement in storage. Similar results were obtained for fruit stored in pilot-sized chambers of 38 bushels capacity (see Table 2).

Soft Scald

1954-55: Controlled-atmosphere storage proved very effective in reducing the occurrence of soft scald. The fruit was first examined December 15; at that time, only apples in storage at 32° F. in normal air showed soft scald, with 34 percent of the fruit affected. By March 20, 52 percent of the apples were affected. As shown in Table 3, all apples stored at 32° F. in controlled atmospheres and which had not been disturbed in storage between December 15 and March 20 remained free of injury.

Curiously, several lots of fruit which had been removed from controlled atmospheres for several days in February for respiration determinations and then returned to the storage chambers developed soft scald. Injury was minor in one lot, but it amounted to 18 percent of the fruit in another lot which had been temporarily removed from the 2.5 percent carbon dioxide—3 percent oxygen atmosphere.

A marked reduction in the incidence of soft scald development at 32° F. was also observed in a companion test of apples stored in sealed plastic film liners in individual storage containers of 1 bushel capacity.

Fruit stored at 36° and 40° F. remained free of soft scald for the entire storage period (Table 3).

1955-56: Soft scald was not a problem during the 1955-56 storage season; therefore, the observed effects of controlled atmospheres in preventing this disorder the previous season were not confirmed.

Carbon Dioxide Tolerance

1954-55: Carbon dioxide injury occurred on Jonathan under the controlled-atmosphere conditions of this test. The injury was characterized by the development of dry, pithy areas in the flesh and near the core of the fruit, together with large cavities or voids in the affected tissues (Fig. 3). Carbon dioxide injury also appeared as flesh-browning which began at the skin and spread to various depths in the flesh.

There was no evidence of carbon dioxide injury when the fruit in the controlled-atmosphere chambers was first inspected on December 15. This was also true on March 20 for fruit stored at 32° and 36° F., except for that stored in 5 percent carbon dioxide with 3 percent oxygen at the latter temperature (Table 3). Flesh injuries of the void or cavity type amounted to 5 percent at this time. Considerable carbon dioxide injury of the flesh resulted from storage at 40° F. to March 20 in atmospheres containing 2.5, 5, and 7 percent carbon dioxide.

Storage to May 2 resulted in carbon dioxide injury in two cases (Table 3). At 32° F. in 7 percent carbon dioxide with 14 percent oxygen, 8 percent of the apples were injured; of this amount, 3 percent showed a necrotic condition of the epidermal tissues with practically no flesh discoloration. The other 5 percent showed surface injury characterized by an external darkening of the anthocyanins in the epidermis to a reddish-blue color (see Fig. 4).

The fruit at 36° F. at 5 percent carbon dioxide—3 percent oxygen had shown injury at the earlier inspection; a slightly greater amount of the same type of injury was evident at the final inspection. Holding the apples for 10 days at 70 to 75° F. after removal from storage did not affect the incidence or severity of damage.

1955-56: As in the previous storage season, symptoms of carbon dioxide injury were less evident with storage at 32° F. than at higher temperatures. Complete freedom from injury in controlled atmospheres occurred in 2.5 percent carbon dioxide with 3 percent oxygen at 32° F. (see Table 1). Apples in two other atmospheres at this temperature, 11 percent carbon dioxide—10 percent oxygen, and 5 percent carbon dioxide—3 percent oxygen, were practically free of surface injury, but they showed a small quantity of flesh injury.

There was no surface injury at the higher storage temperatures with either 2.5 or 5 percent carbon dioxide with 3 percent oxygen, but internal injury affected 0.7 to 1.5 percent of these apples. All of the damage was of minor extent; although the fruit was unmarketable, it was of edible quality in regard to flesh texture and flavor.

The external symptoms of damage caused by carbon dioxide were the development of bluish and brownish discolorations on the epidermis. Internal injury appeared as voids or cavities surrounded by dry, browned tissue in the flesh, rather than in the core area as observed the previous season.

A slight browning of the tissues at the core was noted for all controlled-atmosphere treatments and for regular air storage at 38° F.

This disorder was considered of minor importance in respect to marketability of the fruit and did not develop further upon holding the fruit at room temperatures for 2 weeks.

DISCUSSION AND SUMMARY

An outstanding advantage of controlled-atmosphere storage for Jonathan apples was the control of two serious storage disorders, Jonathan spot and soft scald. Jonathan spot was widespread in regular storage during both seasons, becoming prevalent after about 4 months at 36° F., and 7 months at 32° F. It was effectively controlled at all temperatures (32° to 40° F.) in atmospheres containing 2.5 percent or higher concentrations of carbon dioxide.

Soft scald was practically eliminated by the application of controlled-atmosphere storage during the 1954-55 season when it occurred as a serious storage disorder. Further tests must confirm this result, since soft scald was not a problem in 1955-56. However, the report of other workers (Brooks and Harley, 1934) shows that increased levels of carbon dioxide inhibit soft scald development.

Satisfactory eating quality of the fruit was retained for 7 months in the two seasons tested. Decreased amounts of internal breakdown and a more firm flesh texture upon removal from storage were characteristic of controlled-atmosphere fruit.

Furthermore, apples from controlled atmospheres subsequently remained free of mealiness at room temperatures longer than fruit which had been in regular storage. Retention of good quality and condition for simulated market periods of 2 weeks duration was noted.

Fruit damage attributable to above-normal concentrations of carbon dioxide was the only factor limiting the success of controlled atmospheres for Jonathan apples. Low temperatures (32° F.) minimized the amount of damage compared to higher storage temperatures (36°, 38°, and 40° F.), and carbon dioxide levels of 2.5 percent caused less injury than higher concentrations.

Best storage was attained in 5 percent carbon dioxide with 3 percent oxygen at 32° F. Under these conditions, external and internal injury by carbon dioxide amounted to a maximum of 1.1 percent (Table 2). This degree of injury, although undesirable, seemed of negligible importance when we consider the benefits of controlling Jonathan spot and soft scald and the retention of eating quality.

According to the present evidence, it is believed that Jonathan apples can be stored advantageously from harvest to the following May in controlled atmospheres of 2.5 to 5 percent carbon dioxide and 3 percent oxygen at 32° F.

LITERATURE CITED

Brooks, C., and C. P. Harley (1934). Soft scald and soggy breakdown of apples. Jour. Agr. Res. 49: 55-69.

Fisher, D. V. (1954). Dept. Agr. Expt. Sta., Summerland, B. C., Canada. Private communication.

Hall, E. G. (1955). Commonwealth Scientific and Industrial Research Organization, Division of Food Preservation and Transport, New South Wales, Australia. Private communication.

Phillips, W. R., and P. A. Poapst (1952). Storage of apples. Canada Dept. Agr. Pub. 776. 42 pp.

Plagge, H. H. (1942). Controlled-atmosphere storage for Jonathan apples as affected by restricted ventilation. Refrig. Eng. 43: 215-220.

———, and D. V. Fisher (1942). Pectic change in Jonathan apples is a measure of ripening under differential carbon dioxide treatments. Proc. Amer. Soc. Hort. Sci. 40: 169-171.

Rasmussen, P. Molls (1951). Gas storage of apples in Denmark. Proc. Eighth Int. Cong. Refrig.: 420-422.

Smock, R. M. (1949). Controlled-atmosphere storage of apples. Cornell Ext. Bul. 759. 39 pp.

VanHiele, T. (1951). Gas storage of fruits in the Netherlands. Proc. Eighth Int. Cong. Refrig.: 410-415.

Vickery, J. R.; F. E. Henlin, E. G. Hall and G. B. Tindale (1951). The gas storage of apples and pears in Australia. Proc. Eighth Int. Cong. Refrig.: 416-420.