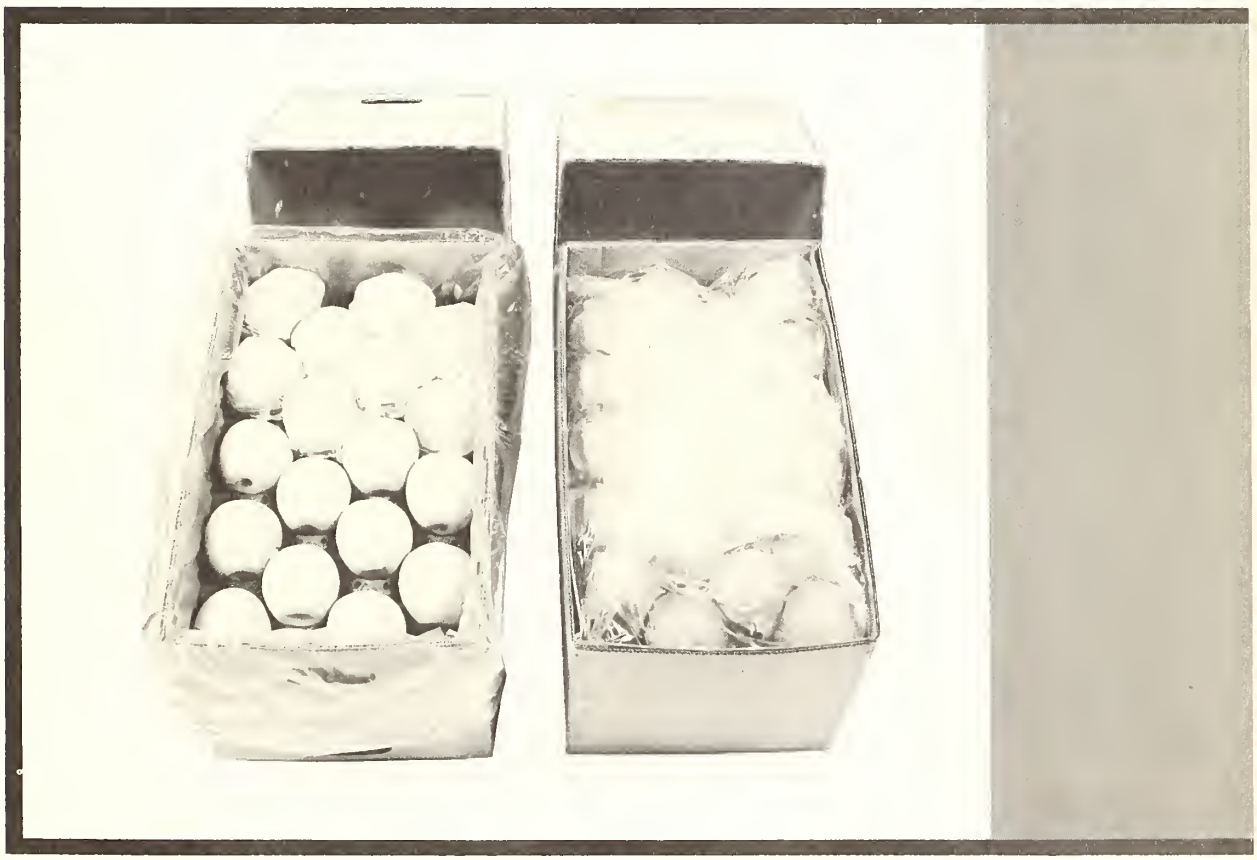
POLYETHYLENE BOX LINERS FOR STORAGE OF GOLDEN DELICIOUS APPLES



Marketing Research Report No. 461

Market Quality Research Division
Agricultural Marketing Service
U.S. DEPARTMENT OF AGRICULTURE

CONTENTS

PREFACE

This is part of a continuing program to improve marketing of agricultural crops.

Carl Vaught and Marguerite Wilcox of the Horticultural Crops Branch, Market Quality Research Division, assisted in collecting and compiling the data.

Union Carbide Plastics Co., a Division of Union Carbide and Carbon Corporation, and the Polychemicals and Film Departments of E. I. du Pont de Nemours and Company assisted in obtaining various types of polyethylene liners.

S. A. Heisey and Sons, Greencastle, Pa., and H. F. Byrd, Inc., Charles Town, W. Va., provided fruit and the use of their storage facilities for some of the tests.

Washington, D.C. March 1961

SUMMARY

Use of polyethylene box liners combined with refrigerated storage can extend the marketing season for Golden Delicious apples, and may allow a premium price for the grower. A study was made of polyethylene liners used for packing apples and the effect of sealed, non-sealed, and perforated liners on the quality of the apples. Golden Delicious apples from orchards in Virginia, West Virginia, Maryland, and Pennsylvania were used in this study, which was carried on for seven seasons, 1953-60. Limited commercial use of film liners for Golden Delicious apples began in 1952 in the Pacific Northwest.

Polyethylene liners may be non-sealed with an overlapping fold at the top, sealed but perforated to provide limited ventilation, or sealed with a tied or heat-sealed closure. Each of these methods of closing film liners will maintain the high humidity within a pack necessary to prevent moisture loss and shriveling. In these experiments, sealed polyethylene liners maintained fruit quality better than non-sealed or perforated liners. However, non-sealed liners with overlap fold are more widely used because they have most of the advantages of sealed liners and offer fewer hazards.

Polyethylene liners may be used in field boxes, or in wood or corrugated boxes for sized and graded fruit. Their primary value is prevention of moisture loss and shriveling of apples during storage. Apples packed in boxes lined with polyethylene lost under 1 percent of weight and did not shrivel during 6 months of storage at 31° to 32° F. Without film liners, weight loss ranged from 4 to 7 percent and shriveling was often severe.

Atmospheres of oxygen and carbon dioxide vary in different types of polyethylene liners in storage at 31° to 32° F. Carbon dioxide usually is maintained within a narrow range but oxygen concentrations are much more variable and, therefore, more difficult to predict. Sealed film liners cannot be relied on to provide all the benefits of storage in a controlled-atmosphere room. However, with attention to details, some benefit from the modified atmosphere in liners can be realized.

Several precautions are necessary for successful use of polyethylene box liners for Golden Delicious apples:

1. Specify 1.5-mil gage polyethylene with a low-density of between about 0.914 to 0.925, as many kinds of polyethylene film made from various resins and manufactured in various gages are available. Films 2.0 mils thick used as sealed liners are too impermeable to respiratory gases and can readily suffocate fruit.

2. Store in polyethylene liners only that portion of the crop intended for storage over 3 months. Apples for long storage should be from clean orchards, firm, and of good quality, with well-developed golden color. The high humidity maintained within film liners improves conditions for growth of decay-producing microorganisms.

3. Avoid packing warm fruit in film liners. Temperatures below 70° F. at time of packaging are desirable. Some packers precool apples in storage a few days before grading and packing into film-lined boxes. Storage at 31° to 32° F. is recommended for Golden Delicious.

4. Non-sealed or perforated liners may increase the hazard of scald on Golden Delicious stored late. Use of oiled wraps will give added protection from storage scald. Another possibility is the use of santoquin, a new chemical scald inhibitor.

5. Polyethylene liners should be either slit open or removed when taken from cold storage for marketing. This is to prevent any harmful effect from increased respiration and inadequate film permeability at higher temperatures. Fruit flavor may be damaged in a short time at warm temperatures if film liners are not opened.

POLYETHYLENE BOX LINERS FOR STORAGE OF GOLDEN DELICIOUS APPLES

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INTRODUCTION

Golden Delicious apples have a skin characteristic that allows relatively rapid moisture loss even in cold storage. It is well known that Golden Delicious apples may become shriveled and spongy after about 3 or 4 months in cold storage even though the relative humidity is as high as 85 percent. The shriveling is apparent when fruit has lost 3 to 5 percent of its original weight. If moisture loss is prevented, Golden Delicious apples have a long life in refrigerated storage and remain free of most physiological storage disorders.

Golden Delicious have excellent dessert quality and are popular with consumers. Production is increasing. With increased supplies becoming available, more of them will be stored for later marketing. Use of moistureproof polyethylene box liners is one method of extending storage life.

This report summarizes the results of a study conducted from 1953 to 1960 on polyethylene box liners for Golden Delicious apples. The purpose of these studies was to evaluate sealed, non-sealed, and perforated liners for preventing moisture loss and aiding quality retention of eastern-grown Golden Delicious in storage. Results of film-liner studies with other apple varieties will be published separately.

REVIEW OF LITERATURE

Films have been tested to reduce shriveling of apples since 1933. In that year Baker (2)[1] reported that Golden Delicious could be individually wrapped in moistureproof cellophane sheets to prevent shriveling. Good results in reducing weight loss with moistureproof cellophane were also reported by Phillips (19). As early as 1941, Plagge and Maney (20) reported that Jonathan apples stored in sealed rubber hydrochloride film box liners (commonly known as Pliofilm)[2] were firmer than check fruit and free from shriveling, while Starking apples did not respond favorably. Baghdadi and Smock (1) compared the effectiveness of various materials, such as waxes, latex emulsions, aluminum foil, cellophane wraps, and Pliofilm wraps and bags for extending the marketable period of Golden Delicious. They found that Pliofilm was the most effective in reducing weight loss and that aluminum foil and cellophane (450 LAT) had some merit. They cautioned that off-flavors were sometimes found if heavier gages of Pliofilm (120 N-2) were used as sealed wraps. McMahon (17) studied the comparative effectiveness of several films, foils, and waxes for reducing transpiration of Golden Delicious in 33° F. storage. He found that wax emulsions were least effective in preventing moisture loss and box liners made of .002-inch aluminum foil were the most effective. Those with lapped, sealed corners were more effective than those with open corners.

[1] Underscored numbers in parenthesis refer to Literature Cited, page 34.

[2] Use of brand names in this report does not constitute endorsement of the products named or imply discrimination against other products. Mention of them is primarily for information of others who may wish to replicate the methodology.

Gerhardt (6) in 1948 compared three types of cellophane and three types of Pliofilm as sealed liners for Golden Delicious. Fruit in 300 or 450 MSAT cellophane and in 120 P4 and P6 Pliofilm was severely injured (off-odor, off-flavor, and tissue injury) even during storage at 31° F. Fruit stored in 300 LSAT cellophane and 75 FF Pliofilm was not injured in storage; however, flavor was impaired when the liners were left sealed during a 7-day ripening period at 65° following storage. These latter two films, if used, should be perforated when the fruit is removed to room temperature. These findings emphasize the hazards of packing apples in unsuitable sealed films.

Early studies with films and foil resulted in little commercial application of the findings to prevent moisture loss of Golden Delicious, probably because of cost and limited availability of films. Foil and colored films were used mainly for decorative wraps in gift packages and in the top layer of cell packs.

About 1950, Gerhardt (6) at Wenatchee, Wash., began testing polyethylene film box liners for pears and Golden Delicious apples. Polyethylene film was relatively inexpensive and had several desirable physical and chemical characteristics not possessed by moisture-retentive wrapping materials previously tested for apples. Gerhardt found that the appearance and dessert quality of Golden Delicious apples in sealed film liners of 1.5-mil polyethylene and Pliofilms 80 FM1 and 80 HP after prolonged storage was still excellent. He recommended that film liners be perforated or slit open on removal from storage to prevent possible injury to the fruit at higher temperatures. With polyethylene liners, weight losses in the fruit were reduced to about 40 percent of those in cell cartons without film protection, shriveling was eliminated, and storage life was prolonged.

In 1952, limited commercial use of sealed 1.5-mil polyethylene and Pliofilm 80 FM1 liners for Golden Delicious was started (7). By 1954 about 100,000 boxes of Golden Delicious apples grown in the Northwest were packed with polyethylene liners according to Schomer, Gerhardt, and Sainsbury (25). Since then use of polyethylene liners to prevent shriveling of Golden Delicious has expanded to other sections of the country.

The authors and co-workers (8, 9, 10, 11) and Workman (30, 31, 32) experimented with eastern-grown Golden Delicious and showed that it was not necessary to use a sealed liner to prevent shriveling. The top of the film liner could be merely folded over the apples to maintain a high humidity, or perforated liners could be used. In 1956 Hardenburg (8) reported that after 6 months storage at 31° F. in boxes lined with polyethylene, Golden Delicious were still in good condition with only negligible shriveling and about 1 percent weight loss.

Hardenburg and Siegelman (9) found that box liners made from polyethylene-coated paper or polyethylene-coated paperboard also markedly reduced weight losses from apples in storage. However, these box liners with open corners were not as effective as polyethylene bag liners. They also reported that in years when scald was present on Golden Delicious, the best control was obtained with sealed film liners used with individual oiled wraps. Scald was more severe in boxes with non-sealed liners than in boxes without film liners. Oiled wraps reduced scald of Golden Delicious whether the film liners were non-sealed or sealed. Stoll and Nyfeler (27) in Switzerland reported increased scald of Golden Delicious stored in polyethylene at 39° F.

Smock and Blanpied (26) showed that either sealed or non-sealed polyethylene liners greatly reduced weight losses in Golden Delicious. However, both types of liners increased scald and decay when fruit was stored at 32° F. until May, and then held 7 days at 70°. Smock and Blanpied showed that controlled-atmosphere storage resulted in firmer fruit with little scald and no decay, and gave a better extension of shelf life after storage than when sealed liners were used.

Hardenburg (8) and Workman (30) showed how a modified atmosphere of increased carbon dioxide and reduced oxygen helped retard ripening of Golden Delicious, but they pointed out the possible dangers of their use due to fruit and film variability.

Padfield (18) in New Zealand reported that polyethylene liners generally were beneficial for Golden Delicious, except for increased internal breakdown in fruit of advanced maturity.

Porritt and Fisher (21) noted that both sealed and, to a lesser degree, non-sealed polyethylene liners retarded yellow color development of Golden Delicious at 32° F. However, fruit from both types of liners ripened to 100 percent yellow color within 2 weeks at 70°.

Dewey, Raphael, and Goff (4) recommended using polyethylene pallet covers for shrivel-susceptible apples like Golden Delicious and Red Steele stored for late marketing in field crates. Moisture loss was decreased by applying film covers immediately after cooling fruit to a desirable storage temperature. Although this markedly reduced shriveling, the high humidity within the pallet covers favored mold growth on the containers.

Schomer, Gerhardt, and Sainsburg (25) have shown that polyethylene liners have some restrictive effect on cooling but the interference usually is not serious. A package having poor cooling characteristics and stacked in a manner that allows little surface presentation to the air stream will not cool much more slowly when lined than when unlined. In one test by these researchers Golden Delicious apples were packed in cell cartons with and without polyethylene liners. The following average time to remove three-fourths of the heat from various packages that were similarly stacked was reported: Wrapped and packed in northwestern wooden box without poly liner - 56 hours; wrapped and packed in cell carton without poly liner - 77 hours; wrapped and packed in cell carton with poly liner - 99 hours. An additional 22 hours was required to remove three-fourths of the field heat from fruit in the film-lined package. However, this additional 22 hours did not appear to be an appreciable factor in the overall storage life of the apples. Researchers found that when fruit had been in storage long enough to reach a stable temperature, the temperature of poly-packed fruit was only a fraction of a degree higher than that of fruit in unlined boxes at the same location.

The use of a film liner will materially alter the cooling rate in a package that is normally open for convection currents to pass through the package. Tests by Schomer, Gerhardt, and Sainsburg with poly liners in field boxes of loose fruit showed that boxes provided with individual film liners and stacked in double rows with ends butting together required 108 hours for three-fourths cooling in comparison with 33 hours for unlined boxes similarly stacked.

Ryall and Uota (23) compared 32°, 40°, and 45° F. storage temperatures for Yellow Newtown apples in sealed polyethylene liners. Usually they found little difference in gas concentrations maintained at these temperatures. Carbon dioxide ranged from 4 to 6 percent and oxygen from 2 to 8 percent. A possible explanation for these somewhat unexpected results is that polyethylene film is more permeable at high than at low temperatures. Workman (30) also studied several storage temperatures for apples in sealed liners and concluded that it is desirable to keep the temperature below 37° F. to avoid very low oxygen and high carbon dioxide concentrations.

Several other investigators have contributed to knowledge of polyethylene and other plastics for fruit storage. Studies on use of film box liners and bags for extending the storage life of numerous varieties of apples and pears have been published (3, 5, 12, 13, 14, 15, 16, 22, 23, 24, 28, 29).

METHODS

Source and Handling of Fruit. --Golden Delicious apples harvested from the Plant Industry Station experimental orchards at Beltsville, Md., were used in most of the tests conducted from 1953 to 1960. In addition, fruit was obtained from nearby commercial orchards in Virginia, West Virginia, and Pennsylvania in some tests. Fruit was picked during the normal harvest season for the area, September 15 to October 15. Usually the Golden Delicious apples were moved to the laboratory immediately after picking, and either packed in film-lined boxes the same day or the following day. Fruit was composited and defective apples were removed before packing. Three or four duplicate boxes of each treatment were packed for each examination.

Northwestern apple boxes with regular paperboard liners and macerated-paper pads were used in most tests (fig. 1). However, field boxes (fig. 2) and corrugated telescope-type boxes were included in several tests (fig. 3, 4). Most tests included fruit both with and without oiled fruit wraps.

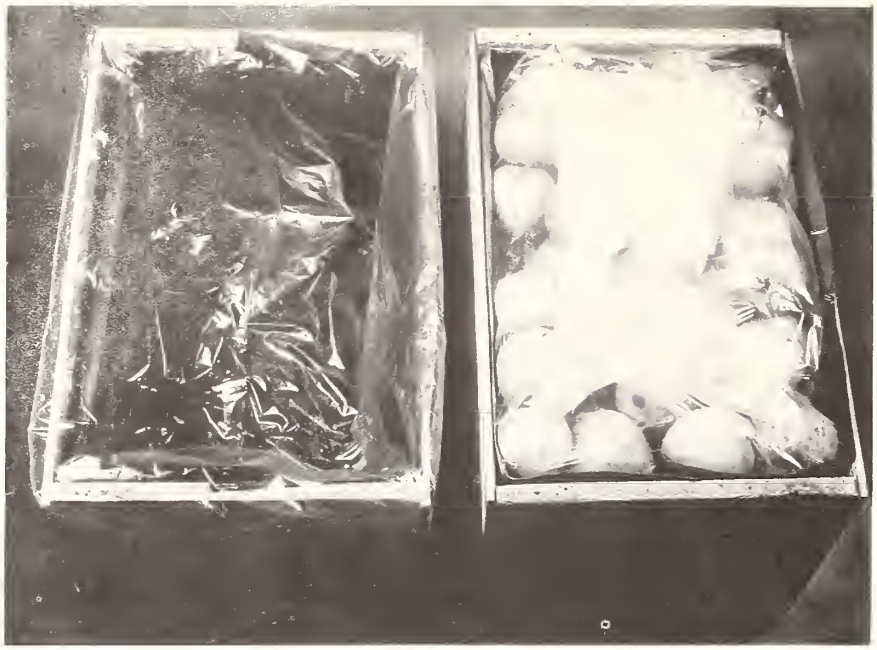

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Figure 1. --Northwestern boxes, with both paperboard and polyethylene liners.

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Figure 2. --Field box of Golden Delicious apples with non-sealed polyethylene liner.

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Figure 3. --Corrugated tray-packed boxes of Golden Delicious apples. The box on the right has overlapped (non-sealed) polyethylene liner. The individual fruit wraps provided added protection from scald for these apples stored 6 months at 31°-32° F.

Polyethylene Film. --There are many types of polyethylene film made by different manufacturers using low-, medium-, and high-density polyethylene resins. The polyethylene films used in these tests were all of the low-density type with densities ranging from 0.914 to 0.928.

Polyethylene film is a good produce-packaging material: it is inexpensive, transparent, odorless, tasteless, nontoxic, chemically inert, flexible at low temperatures, easy to handle, tough, resistant to tearing, has good slip characteristics, and is heat sealable at controlled temperatures. It is highly resistant to transmission of water vapor and stands up well under either dry or moist storage conditions.

Conventional low-density polyethylene film is also relatively permeable to carbon dioxide and oxygen when compared with other packaging films and several times more permeable to carbon dioxide than to oxygen. Even with its relatively high permeability to the respiratory gases, polyethylene cannot be used as a sealed box liner for fruit held at warm temperatures. The film would need to be perforated to provide sufficient gas exchange for the faster respiration of apples at warm temperatures.

Gussetted box liners commercially fabricated of 1.5-mil polyethylene (.0015 inch) film were used. A heavier 2.0-mil film was included in some tests for comparison. Dimensions of the film liners were 19 1/2 x 12 1/2 x 26 1/2 inches for Northwest wooden boxes and 21 1/2 x 16 x 40 inches for tray-pack corrugated boxes. Individual polyethylene apple wraps would require from five to eight times as much film per box as is used in these liners, so liners are a more economical method of preventing weight loss.

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Figure 4.--Corrugated tray-packed boxes of Golden Delicious apples showing tied (sealed) polyethylene liner at the right and at left inverted tray over liner.

Three methods of closure of liners after filling were tested: Non-sealed with film overlapped at the top; sealed with film gathered, twisted, and tied; and sealed but perforated. The perforated liners had four 1/8-inch holes, with one at each top corner. When liners were used in tray-pack cartons, the bottom tray was under the film liner and the top inverted tray was placed above the liner after closing and served as a top pad. This gave a fairly tight closure even when the liner was only folded over the fruit.

Storage Procedure.--The storage period for Golden Delicious was usually 6 months at 31° to 32° F. In 2 of the years studied, part of the fruit was examined after 3 months' and part after 6 months' storage. In 1 year, samples of the Golden Delicious apples were examined after 2, 4, 6, and 8 months' storage. Relative humidity in cold storage averaged 85 to 90 percent.

After removal from cold storage, the apples were examined, and then held 6 days at 70° F. and 45 to 50 percent relative humidity to simulate a marketing period, after which they were examined a second time. In some tests the polyethylene liners were removed from the boxes during this holding period at warm temperature; in others, the liners were left in but were slit 6 inches or were opened at the top.

Fruit Evaluation and Gas Analysis.--Gross and tare weights of all boxes were recorded at each examination to obtain net weight loss of the apples. Other data were collected on shriveling, firmness, decay, scald, ground color, ripeness, flavor, and appearance. In addition, the oxygen and carbon dioxide contents of the atmosphere in the boxes were determined with a portable Orsat analyzer on 100-ml. samples withdrawn with a No. 15 hypodermic needle. The hole made through the film at each analysis was immediately sealed with cellulose tape. Fruit firmness was measured with a Magness-Taylor pressure tester with a 7/16-inch plunger on a 20- or 30-fruit sample.

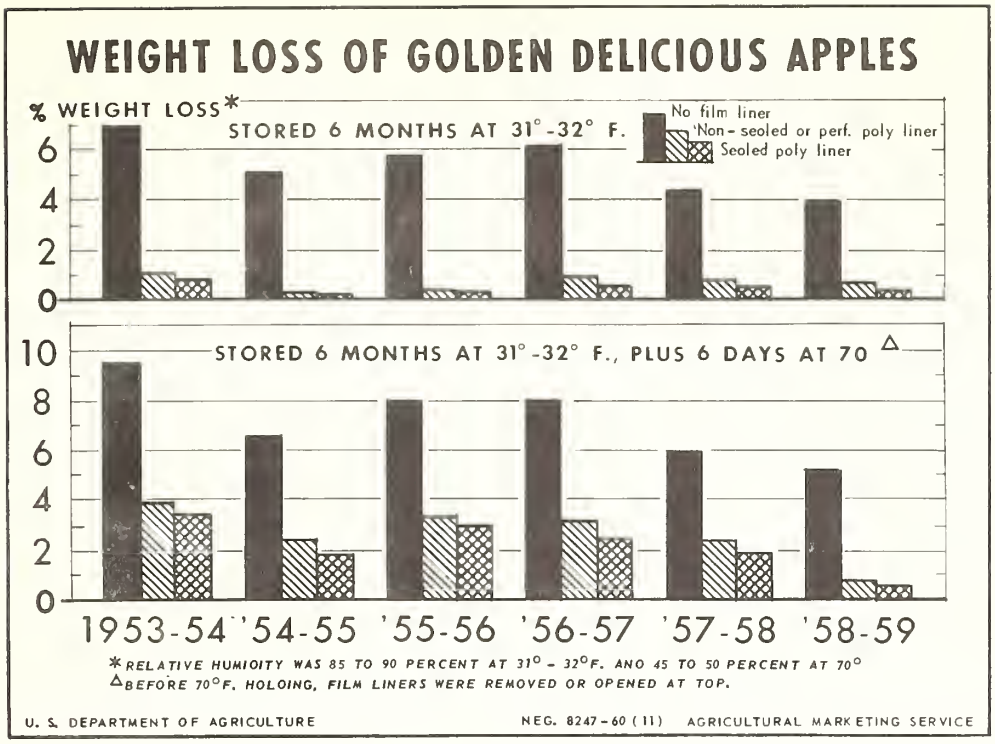

Figure 5

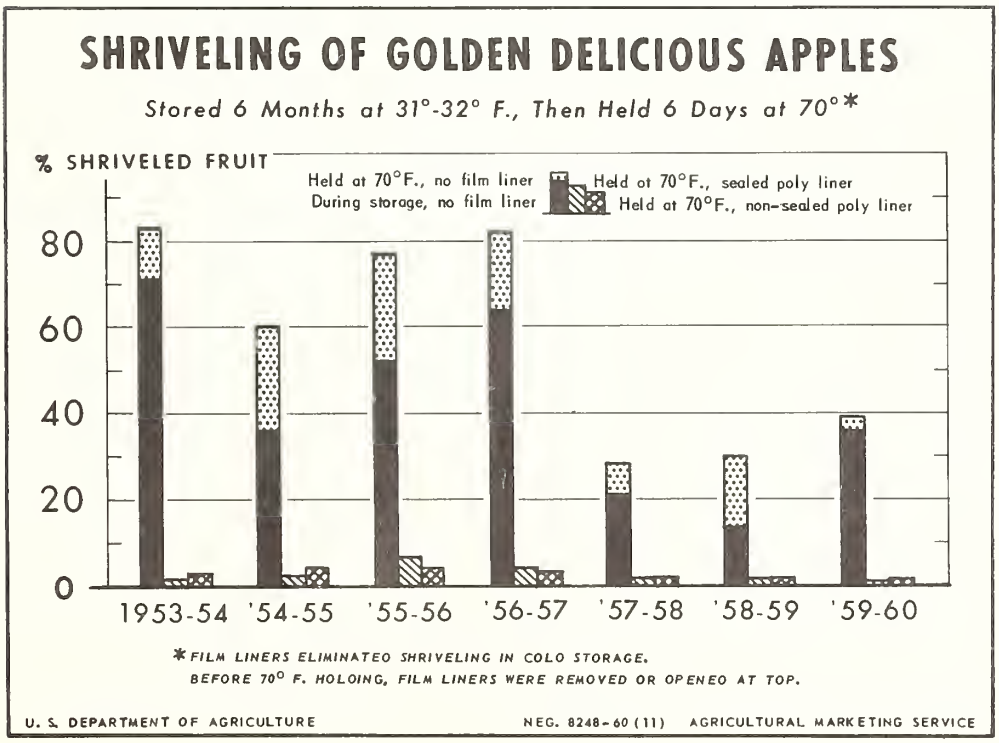

Figure 6

In one test respiration rate of fruit was determined during the first 3 days at 70° F. after removal from storage. The respiration values were obtained by absorption of CO_2 in standard KOH, precipitation of the carbonate with $BaCl_2$, and titration with 0.48N HCl. Respiration is expressed as milligrams of CO_2 per kilogram of fruit per hour.

RESULTS

Weight Loss and Shriveling

Golden Delicious apples stored without film lost weight and shriveled even when held in cold storage with a relative humidity as high as 85 to 90 percent. In six tests, weight losses after 6 months' storage at 31° to 32° F. ranged from 4 to 7 percent in bushel boxes with regular paperboard liners (fig. 5). When these same apples were held an additional 6 days at 70° to simulate a marketing period, weight losses ranged from 5 to over 9 percent. A weight loss of 3 to 4 percent was sufficient to produce some spongy and visibly shriveled apples. In 1953-54 when weight loss reached 6.9 percent during 6 months' storage with paperboard liners, 71 percent of the apples were shriveled (fig. 6). In 1958-59 when weight loss was 4.1 percent after 6 months, only 13 percent of the apples were shriveled. Usually Golden Delicious apples in film-lined boxes were still firm and marketable after 6 months' storage (fig. 7).

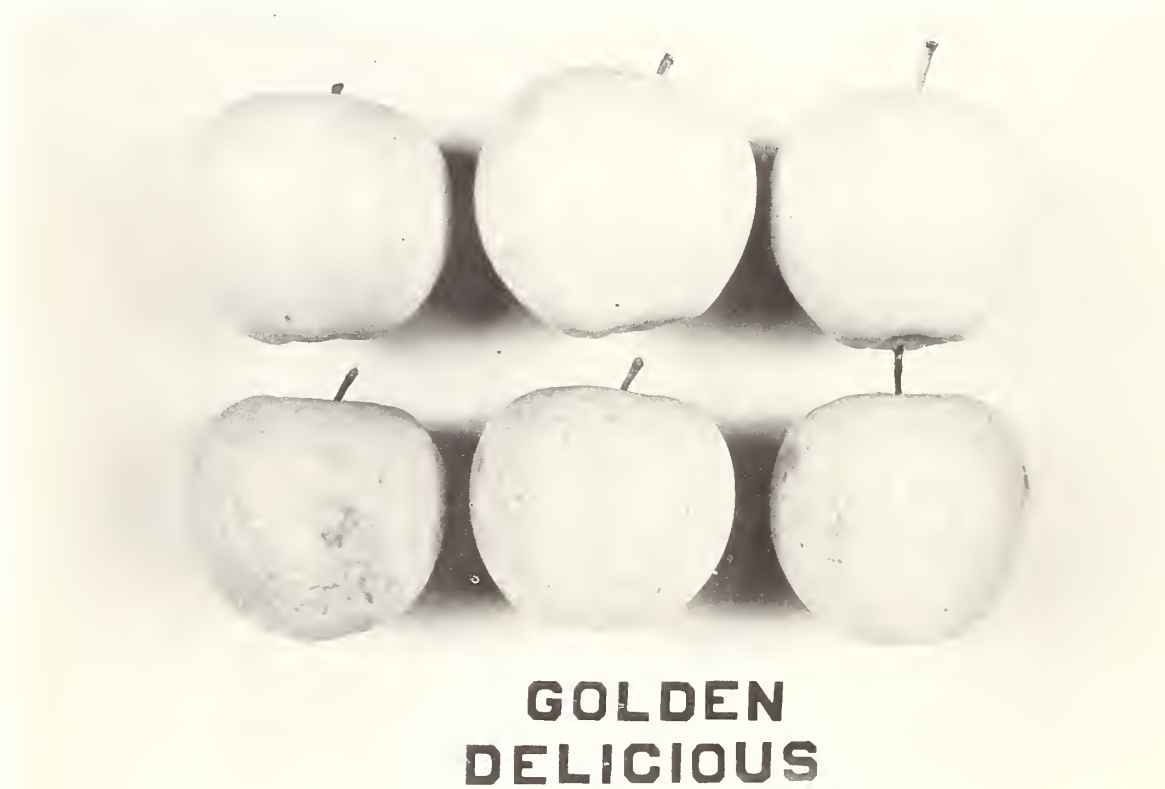

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Figure 7.--Apples after 6 months' storage at 32° F. Those in top row were protected with moistureproof polyethylene box liner. The control apples below had no film liner; note shriveling.

Polyethylene box liners were very effective in preventing shriveling caused by moisture loss. Weight loss of fruit stored in boxes with film liners was less than 1 percent after 6 months' storage at 31° to 32° F. and there was no shriveling (fig. 5). In one season when apples were stored 8 months (until May) in polyethylene-lined boxes, weight loss was still less than 1 percent, whereas weight loss was 5.3 percent without film liners (table 1). Measurements of the humidity with an electric hygrometer showed that the relative humidity within film-lined boxes in cold storage was maintained at 99 to 100 percent.

In some years the beneficial effect of moistureproof polyethylene liners for Golden Delicious apples was apparent after only 3 months' storage at 31° to 32° F. However, the value of film liners in preventing weight loss and shriveling was more pronounced after long storage of 4 to 6 months. When moisture loss was prevented through use of film liners the appearance of fruit on removal from storage was superior to that of unprotected fruit.

Polyethylene liners do not need to be sealed to prevent weight loss and shriveling. Non-sealed liners, where the film is overlapped at the top, gave excellent protection against moisture loss (fig. 5). Film liners which were tied at the top and then perforated with four 1/8-inch holes to give limited ventilation also gave excellent protection against moisture loss (fig. 8). Each of the three types of liners tested (sealed, non-sealed, and perforated) kept weight loss under 1 percent and prevented shriveling during storage at 31° to 32° F.

Table 1.--Weight losses from Golden Delicious apples stored at 31° to 32° F. in boxes with with various types of liners, and then held 6 days at 70° F., 1958-59[1]

(Values based on triplicate boxes)

Time of examination and type of box and liner	Weight loss after storage for--			
	2 months	4 months	6 months	8 months
On removal from 31° to 32° F. storage:	Percent	Percent	Percent	Percent
NW box, paperboard liner, no film	2.2	3.1	4.1	5.3
NW box, perf. poly. (1.5-mil Alathon 14)	0.4	0.4	0.7	0.6
NW box, sealed poly. (1.5-mil Alathon 14)	0.2	0.4	0.2	0.4
NW box, sealed poly. (1.5-mil Alathon 10)	0.3	0.3	0.4	0.5
NW box, sealed poly. (2.0-mil DFDA-0210)	0.1	0.0	0.7	0.6
Tray carton, sealed poly. (1.5-mil Alathon 10)	0.4	0.6	0.8	0.5
After storage plus 6 days 70° F:				
NW box, paperboard liner, no film	4.0	4.3	5.3	6.2
NW box, perf. poly. (1.5-mil Alathon 14)	0.5	0.5	0.9	0.6
NW box, sealed poly. (1.5-mil Alathon 14)	0.3	0.4	0.4	0.6
NW box, sealed poly. (1.5-mil Alathon 10)	0.3	0.3	0.5	0.5
NW box, sealed poly. (2.0-mil DFDA-0210)	0.2	0.2	0.9	0.8
Tray carton, sealed poly. (1.5-mil Alathon 10)	0.7	0.9	0.8	0.8

[1] Perforated film liners had four 1/8-inch holes, with one at each top corner. Before holding at 70° F., all film liners were slit 6 inches for ventilation. Relative humidity at 31° to 32° F. was 85 to 90 percent and at 70°, 45 to 50 percent.

Table 1 gives the weight losses from apples stored 2, 4, 6, and 8 months in sealed liners made from two different polyethylene resins (Alathon 10 and Alathon 14) of the same gage. Both types were highly moistureproof and there was no marked difference in their effectiveness. One type of 2.0-mil polyethylene liner was compared with conventional 1.5-mil liners. The 2.0-mil liners prevented weight loss but were less permeable to the respiratory gases.

Polyethylene liners were effective in retarding weight loss and eliminating shriveling in both Northwestern wood boxes and in corrugated tray-pack boxes (table 1).

The extent of weight loss during a simulated marketing period of 6 days at 70° F. following cold storage is illustrated in figures 5 and 8; extent of shriveling is shown in figure 6. If film liners are removed when boxes are withdrawn from cold storage for marketing or the top is folded back over the sides, weight loss usually increased 1 to 4 percent in 6 days at 70°, and some shriveling developed. However, the amount was still much less than that occurring in boxes stored without film liners. When film liners were left in the boxes during marketing, total weight loss was still less than 1 percent after 4 to 8 months' storage plus 6 days at 70° (fig. 8). This was true even though the liners were slit 6 inches to provide the increased ventilation necessary at the higher temperature.

Firmness

Firmness of the apples at harvest as measured with a pressure tester ranged from 14 to 18 pounds in different years. The effect of various box liners on firmness after 6 months' storage and after an additional 6 days at 70° F. is shown in figure 9. Sealed polyethylene liners had a slight beneficial effect in slowing the rate of softening and ripening of Golden Delicious. In 6 of the 7 years studied, apples stored in sealed polyethylene-lined boxes were firmer after 6 months' storage at 31° to 32° F. than apples in boxes without film liners. The difference in firmness after storage was not always large; the fruit packed in sealed liners ranged up to 2.5 pounds firmer, averaging 1.3 pounds firmer than fruit in boxes without liners. Apples stored 6 months in sealed liners had an average firmness of 12.4 pounds compared to 11.1 pounds without liners. This difference in firmness is attributed to the high humidity and the modified atmosphere of increased carbon dioxide and reduced oxygen maintained within film liners.

Part of this firmness difference carried through the simulated marketing period, even though liners were removed or slit open when fruit was taken from cold storage. Apples stored 6 months at 31° to 32° F. in sealed polyethylene liners and then held 6 days at 70° were still firmer than other lots stored without film.

Apples stored in non-sealed or perforated polyethylene liners, on the other hand, usually were no firmer than control fruit when examined following storage. Fruit in boxes without film liners became spongy as it lost weight. For this reason the pressure tester did not give a good relative measure of firmness.

The firmness of Golden Delicious apples after 2, 4, 6, and 8 months at 31° to 32° F. in various types of box liners is given in table 2. The same conclusions on effect of film liners on firmness are apparent. Apples stored in sealed polyethylene liners were 1 to 3 pounds firmer than control fruit, but apples stored in perforated liners were no firmer than the controls.

Color

As Golden Delicious apples ripen in storage they gradually develop more yellow color. Color, therefore, is one index of degree of ripeness. In six tests in which color was measured with U.S. Department of Agriculture ground-color charts, the ripest fruit after 6 months' storage was in boxes without film liners (table 3). Sealed polyethylene liners delayed ripening, as apples in them had less yellow color after storage. Non-sealed

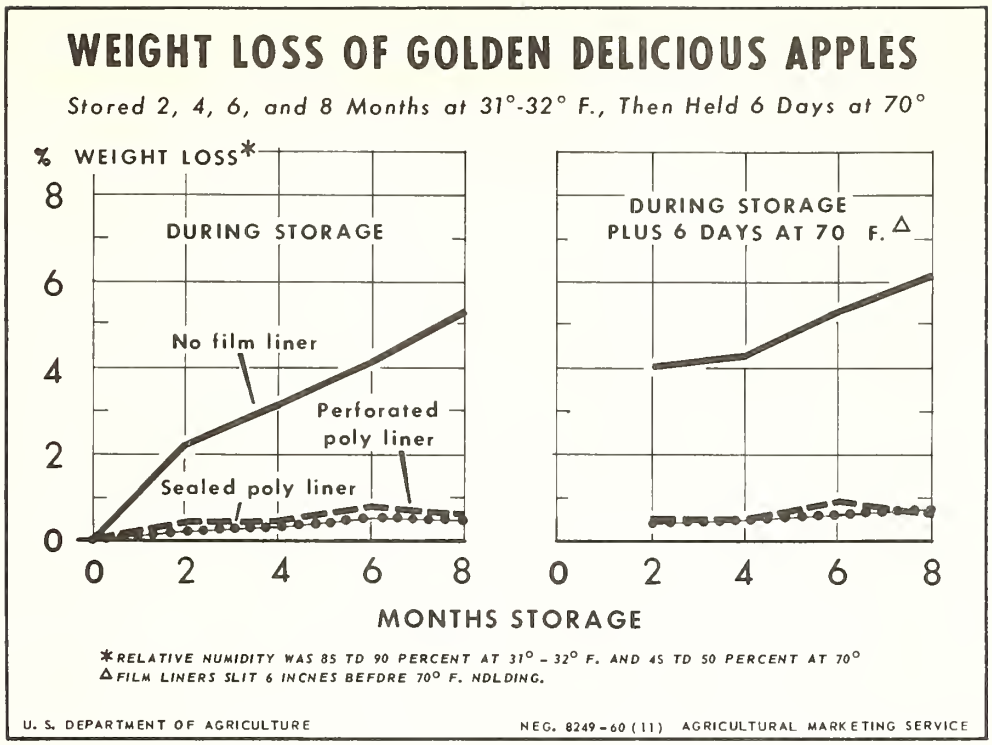

Figure 8

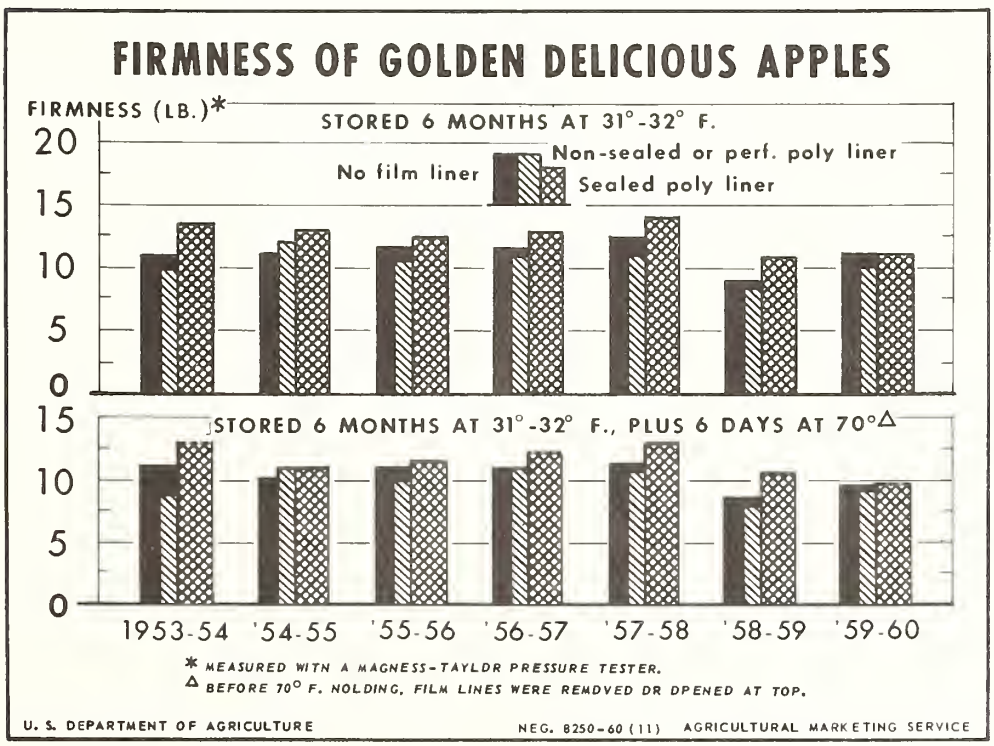

Figure 9

Table 2.--Firmness of Golden Delicious apples stored at 31° to 32° F. in boxes with various types of liners, and then held 6 days at 70° F., 1958-59[1]

Time of examination and type of box and liners[2]	Firmness			
	2 months	4 months	6 months	8 months
On removal from 31°-32° F. storage:	Pounds	Pounds	Pounds	Pounds
NW box, paperboard liner, no film	11.8	9.4	8.7	8.1
NW box, perf. poly. (1.5-mil Alathon 14)	11.7	9.3	8.5	8.2
NW box, sealed poly. (1.5-mil Alathon 14)	12.7	11.5	10.1	10.2
NW box, sealed poly. (1.5-mil Alathon 10)	13.3	11.7	10.7	10.5
NW box, sealed poly. (2.0-mil DFDA-0210)	13.2	12.2	11.2	11.1
Tray carton, sealed poly. (1.5-mil Alathon 10)	12.9	11.8	11.3	10.6
After storage plus 6 days 70° F.:				
NW box, paperboard liner, no film	10.2	8.7	8.4	8.3
NW box, perf. poly. (1.5-mil Alathon 14)	9.5	8.8	8.1	8.1
NW box, sealed poly. (1.5-mil Alathon 14)	11.0	10.4	10.1	10.1
NW box, sealed poly. (1.5-mil Alathon 10)	11.4	10.6	10.4	10.2
NW box, sealed poly. (2.0-mil DFDA-0210)	11.8	11.1	10.8	10.6
Tray carton, sealed poly. (1.5-mil Alathon 10)	11.9	10.6	10.4	10.4

[1] Firmness at harvest September 29, 1958 was 14 pounds.
[2] Perforated film liners had four 1/8-inch holes with one at each top corner. Before holding at 70° F., all film liners were slit 6 inches for ventilation.

Table 3.--Color of Golden Delicious apples after storage for 6 months at 31° to 32° F. in boxes with various types of liners[1]

Date and year of harvest	Color rating at harvest	Color rating after storage		
		Paperboard liner (control)	Non-sealed polyethylene liner	Sealed polyethylene liner
September 24, 1953	2.3	3.5	2.9	2.8
September 28, 1954	2.3	3.1	3.1	2.9
September 13, 1956	1.8	3.1	2.9	2.3
October 3, 1956	2.2	3.7	3.5	3.3
October 15, 1956	3.0	4.0	4.0	3.9
September 30, 1957	2.6	3.8	3.6	3.2
Mean of 6 tests	2.4	3.5	3.3	3.1

[1] Color rated with a standard ground-color chart issued by the U. S. Department of Agriculture. Values shown are the average color on 20 or 30 apples of each lot. On the 1- to 4-rating system used 1 = green and 4 = yellow. Polyethylene liners were 1.5-mil gage.

or perforated liners usually had an intermediate effect. The average color ratings of fruit stored 6 months at 31° to 32° F. in boxes with paperboard liners, non-sealed polyethylene liners, and sealed polyethylene liners were 3.5, 3.3, and 3.1, respectively. Avoid packing green fruit in polyethylene, as liners slow the ripening process. Golden Delicious should be packed when their color is well developed, but before they are too mature for long storage.

Decay and Breakdown

The amount of decay, mainly blue and gray mold rots, which developed in 12 storage tests with polyethylene liners is given in table 4. In 6 of 12 tests, decay was only slight in control boxes without film liners, amounting to 2 percent or less after 6 months' storage at 31° to 32° F. However, after storage, plus 6 days at 70° in 6 of the 12 tests, decay in control boxes amounted to 10 percent or higher. There was no indication that packing apples in film-lined boxes increased decay when storage was at 31° to 32°. In the six tests where decay was extensive, it was usually highest in the control boxes with paperboard liners. The least decay was usually in boxes with sealed film liners. The buildup of carbon dioxide (3 to 6 percent) within these film box liners during storage may have helped to keep decay low, even though humidity was maintained at a very high level.

Table 4.--Decay of Golden Delicious apples stored 6 months at 31° to 32° F. in boxes with various types of liners, and then held 6 days at 70° F.[1]

Time of examination and date test initiated	Decay (percent)		
	Control, no film	Non-sealed or perforated poly liner	Sealed poly liner
After 6 months at 31° to 32° F.:			
September 24, 1953	16	3	2
September 28, 1954	1	2	1
September 15, 1955	2	1	1
September 27, 1955	1	2	1
October 7, 1955	10	7	6
September 13, 1956	1	1	0
October 3, 1956	1	1	1
October 15, 1956	10	2	4
September 30, 1957	11	9	4
September 29, 1958	6	7	1
September 23, 1959	4	0	1
September 29, 1959	1	0	0
Mean of 12 tests	5.3	2.9	1.8
After 6 months at 31° to 32° F. plus 6 days at 70° [2]:			
September 24, 1953	22	3	3
September 28, 1954	3	3	1
September 15, 1955	3	1	2
September 27, 1955	2	7	3
October 7, 1955	20	16	11
September 13, 1956	1	1	0
October 3, 1956	4	3	2
October 15, 1956	22	4	7
September 30, 1957	25	18	7
September 29, 1958	12	16	2
September 23, 1959	10	1	3
September 29, 1959	1	2	0
Mean of 12 tests	10.4	6.3	3.4

[1] Includes tests in 7 different seasons. Values are based on decay found in duplicate or triplicate boxes.

[2] Before holding at 70° F., all film liners were either removed, slit, or opened at the top.

Decay increased during the 6-day holding period at 70° F. following storage, but the same relationships were maintained. Decay average 10.4 percent without film liners, 6.3 percent in non-sealed or perforated polyethylene liners, and 3.4 percent in sealed polyethylene.

During 1955 and 1956, Golden Delicious were picked three times each season 10 to 20 days apart, from the same trees. Both years the highest decay during storage developed in fruit from the latest or most mature picking (table 4). Decay from storage plus holding was usually due to gray-mold nesting. Individual oiled wraps were of some value in reducing this gray mold rot.

Decay during the 1958-59 season was slight to negligible at the 2- and 4-month examinations. However, after 6 to 8 months' storage in perforated-polyethylene-lined boxes, followed by a 6-day holding period at 70° F., overall decay had increased to 16 to 19 percent (table 5). This was one of the few tests in which decay was higher in perforated or non-sealed film than in control boxes.

There was no indication that use of film liners increased any type of internal breakdown in Golden Delicious apples. Many hundreds of apples were cut for this examination.

Table 5.--Decay in Golden Delicious apples (1958-59 season) stored 2, 4, 6, and 8 months at 31° to 32° F. in boxes with various types of liners, and then held 6 days at 70° F.[1]

Time of examination and type of box and liner[2]	Amount of decay after--			
	2 months	4 months	6 months	8 months
On removal from 31° to 32° F. storage:	Percent	Percent	Percent	Percent
NW box, paperboard liner, no film	1	0	6	2
NW box, perf. poly. (1.5-mil Alathon 14)	1	1	7	12
NW box, sealed poly. (1.5-mil Alathon 14)	0	1	1	1
NW box, sealed poly. (1.5-mil Alathon 10)	0	0	2	5
NW box, sealed poly. (2.0-mil DFDA-0210)	0	1	0	2
Tray carton, sealed poly. (1.5-mil Alathon 10)	1	0	2	1
After storage plus 6 days 70° F.:				
NW box, paperboard liner, no film	1	1	12	5
NW box, perf. poly. (1.5-mil Alathon 14)	2	2	16	19
NW box, sealed poly. (1.5-mil Alathon 14)	0	3	2	2
NW box, sealed poly. (1.5-mil Alathon 10)	1	1	3	8
NW box, sealed poly. (2.0-mil DFDA-0210)	1	3	1	4
Tray carton, sealed poly. (1.5-mil Alathon 10)	1	1	2	2

[1] Each value is based on decay in 3 boxes; a different set of boxes was examined after 2, 4, 6, and 8 months' storage.

[2] Perforated film liners had four 1/8-inch holes, one at each top corner. Before being held at 70° F., all film liners were slit 6 inches for ventilation.

Splitting or cracking of the fruit sometimes was increased during late storage in moistureproof liners, partially offsetting the value of liners in preventing weight loss or shriveling. This splitting or cracking was worse on lots picked at an advanced stage of maturity. In these tests, the number of split apples varied from 0 to 4 percent after 6 or 8 months' storage. It was more extensive in the bottom layer where fruit sometimes was in contact with water which had condensed on the sides or top and run to the bottom. The amount of this free water in a film liner after 6 months at 31° to 32° F. plus 6 days at 70° was about 1 or 2 tablespoonfuls. In tests in which both wrapped and nonwrapped fruit were packed in perforated film liners, more splitting occurred when no wraps were used.

High humidity caused some surface mold to develop on the skin and in the stem and calyx cavities of fruit in film-lined boxes. Much of this surface mold disappeared a short time after the boxes were opened, so it was not considered a serious defect. However, Gerhardt (6) found a dark surface mold on unwashed Golden Delicious stored in polyethylene that impaired their appearance. Most Golden Delicious apples now being stored in film liners in the Northwest are previously washed with a fungicide to retard mold growth. However, there is little evidence as to the effectiveness of such fungicidal washes.

Storage Scald

Usually scald is not a serious storage disorder of Golden Delicious apples. In most tests no scald developed during 6 months' storage at 31° to 32° F. However, when fruit was held 6 days at 70° following storage, scald sometimes developed (figs. 10, 11). The extent of scald ranged from 0 to 43 percent in different years. Most of it was slight and seldom was as severe as shown in figure 11.

The effect of polyethylene liners on incidence of scald was not always the same but trends were evident. In 8 of 13 tests made scald was most extensive in boxes with non-sealed or perforated film liners packed without oiled wraps. In other words, use of non-sealed or perforated liners increased scald over that occurring in boxes without film liners in some years.

Scald in sealed film-lined boxes was often slightly less than that in control boxes without film liners. For the tests summarized in figure 10, scald averaged 5.1 percent with no film liner, 15.5 percent with non-sealed or perforated liners, and 4.5 percent with sealed liners. This was without use of individual oiled-paper wraps for scald protection.

Oiled wraps reduced the amount of scald of Golden Delicious whether film liners were non-sealed or sealed (fig. 10). In six tests with non-sealed or perforated liners where comparisons with and without oiled wraps were possible, scald averaged 15.5 percent without wraps and 3.0 percent with oiled wraps. The least scald (0.5 percent) developed when both sealed polyethylene liners and individual oiled wraps were used. A new chemical scald inhibitor, santoquin, also can provide some protection from scald.

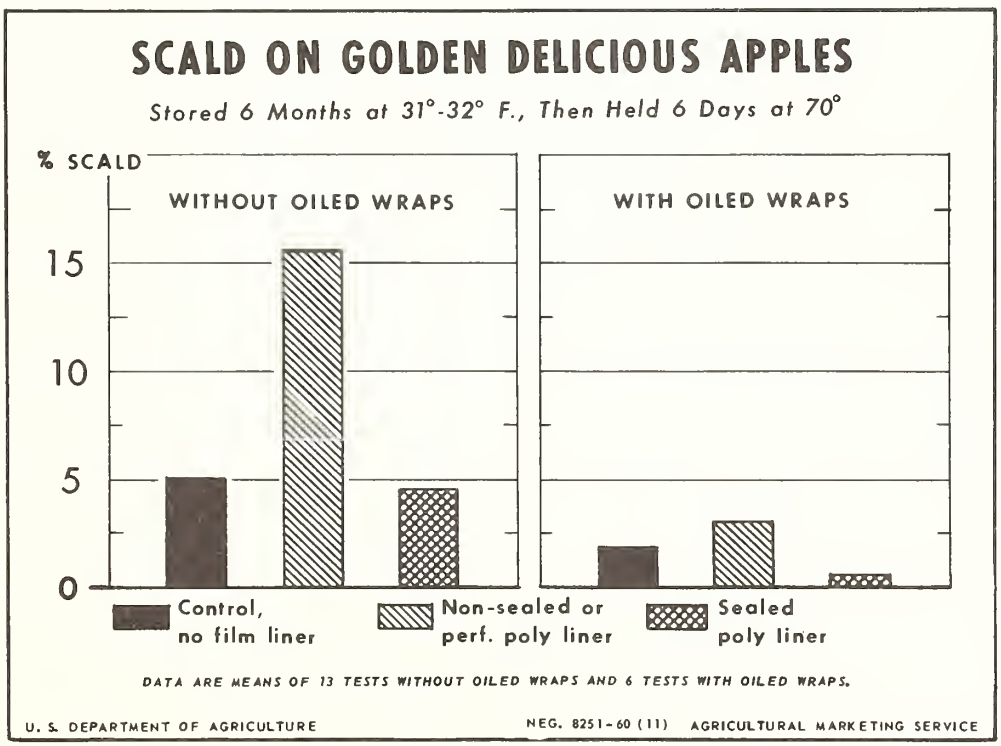

Figure 10

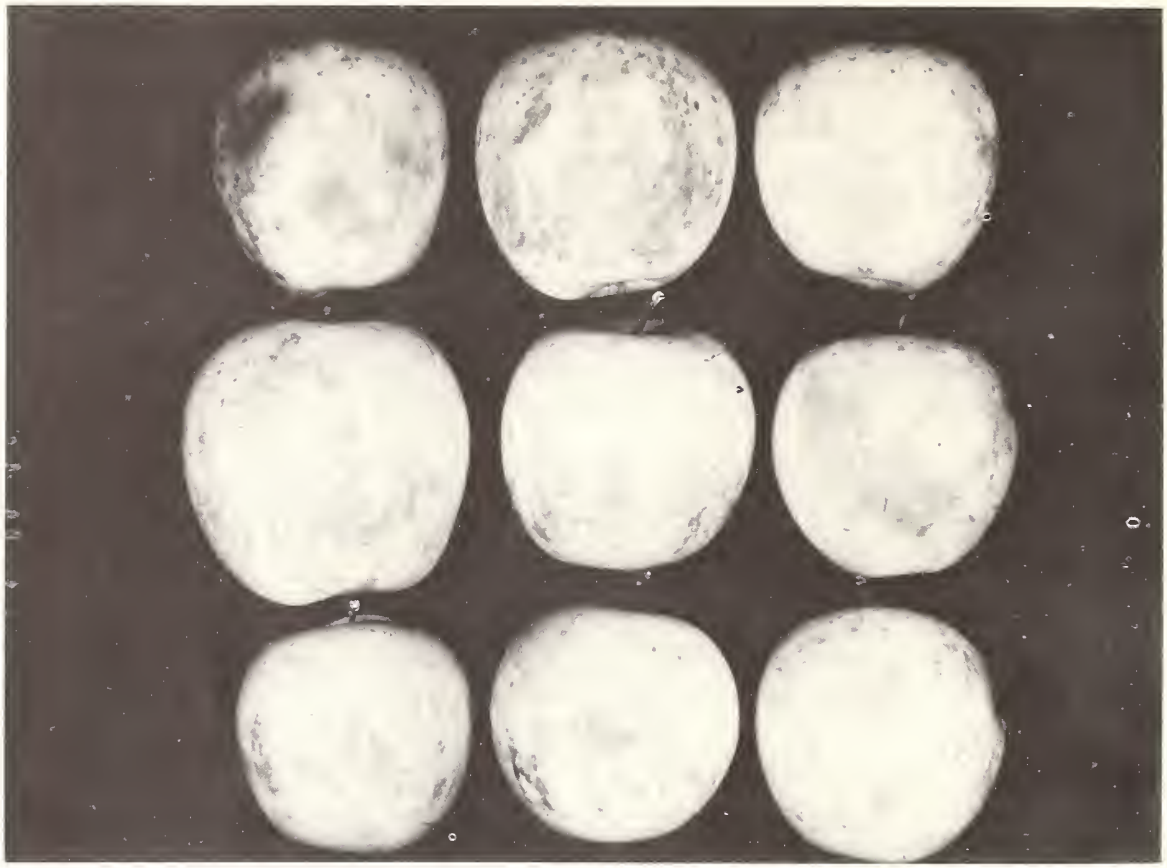

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Figure 11. --Storage scald on Golden Delicious apples after prolonged storage in non-sealed film liners. It was seldom this severe.

Scald development on apples in film-lined boxes may be related to the oxygen-carbon dioxide relationships maintained within liners. In non-sealed or perforated liners atmospheres of 2 to 3 percent carbon dioxide and 18 to 19 percent oxygen were common and scald was sometimes extensive. In sealed liners, atmospheres of 4 to 6 percent carbon dioxide and 5 to 15 percent oxygen were found in different lots. The oxygen level appeared to be critical in scald development. When the oxygen level in sealed film-lined boxes ranged from 5 to 12 percent, scald was less than in boxes without film liners. When the oxygen level in sealed liners was as high as 14 to 15 percent, scald was not reduced and sometimes was as extensive as in non-sealed liners. The best control of scald on Golden Delicious in sealed liners occurred when oxygen was maintained at a low level of 5 to 7 percent during the first few months of storage. This has been discussed with red-skinned varieties in other reports (10, 30).

Flavor and Dessert Quality

Fruit held 6 months in cold storage in film-lined boxes was generally preferred by a taste panel to that stored in regular packs. When examined after 6 days of ripening at 70° F., fruit that had been stored in film liners was still firm and had a crisp juicy texture, superior in dessert quality to that packed without film liners. The flavor of film-packed fruit was sometimes mild, particularly in sealed liners, but was rated higher than regular-packed fruit and was free of shriveling. Fruit stored 6 months without the protection of film liners was inferior to that in polyethylene, chiefly because of the amount of shriveling, advanced ripeness, and toughness of texture. Usually there was little difference in flavor or dessert quality of apples in sealed or non-sealed liners, other than

that fruit from sealed liners was not as ripe and had a slightly firmer texture. These differences in dessert quality of fruit from boxes lined and boxes not lined with film were much less apparent when storage was only 3 or 4 months at 31° to 32° F.

These conclusions on dessert quality also applied when film liners were removed or slit open on removal from storage to provide additional ventilation at warm temperatures. Even 1.5-mil polyethylene sealed liners did not have adequate permeability for use at room temperature without possible injury to fruit flavor. In 2 years' trials when liners were left sealed for 6 days at 70° F. following storage, oxygen was depleted to an average of 1.5 percent and carbon dioxide averaged 10 percent in the boxes. This abnormal atmosphere caused some apples to be off flavor, described by some as winey or slightly fermented.

Thicker 2.0-mil polyethylene sealed liners, being less permeable, may suffocate apples even during refrigerated storage. Two types of 2.0-mil film liners (DFDB-0210 and DFDA-0111) were tested with Golden Delicious during the 1958-59 season. After 6 months' storage in these sealed liners, 20 to 25 percent of the fruit was visibly injured from the abnormal atmosphere and much of it badly off flavor or fermented. The atmosphere within some of these 2.0-mil liners averaged less than 1 percent oxygen and 10 to 13 percent carbon dioxide. More extensive discussion of the atmospheres found within film liners is contained in another section of this report.

Effect of Liners on Respiration Rate

It was shown by Gerhardt (6) that Golden Delicious apples previously held in various sealed film liners respired at a lower rate during cold storage than did comparable fruit without film protection. The respiration rate at 31° F., expressed as milligrams of CO_2 per kilogram of fruit per hour, was 4.6 mgs. for fruit in regular cell cartons without film and 3.4 mgs. in sealed polyethylene liners.

The respiration data given in figure 12 show the rates at 70° F. when fruit is moved from 31° to 32° F. storage after 4, 6, and 8 months. The poststorage respiration rate of Golden Delicious from sealed polyethylene liners was considerably less than that of fruit from perforated polyethylene liners or from control boxes without film. Workman (30) reports that sealed liners have also reduced respiration of Rome Beauty apples.

Atmospheres in Film-Lined Boxes

Atmospheres During Storage. --The oxygen content of the atmosphere in boxes without film liners was close to that in normal air, 21 percent, and the carbon dioxide was less than 0.5 percent during storage.

In five tests of Golden Delicious apples stored at 31° to 32° F. in lidded northwestern boxes with non-sealed polyethylene liners overlapped at the top after filling, oxygen was maintained at an average level of 17 to 19 percent and carbon dioxide at 2 to 3 percent (fig. 13). In five other tests in which liners were tied but were perforated with four 1/8-inch holes, the oxygen and carbon dioxide levels were quite similar to those maintained in non-sealed liners but with less variation. The perforated liners in wood boxes maintained oxygen at about 19 percent and carbon dioxide at 2 percent during storage (fig. 14).

The atmosphere in sealed polyethylene liners (1.5-mil) was modified much more extensively. The oxygen in sealed liners ranged from an average of 4.5 percent to an average of 14 percent in different tests, while carbon dioxide ranged from 4 to 6 percent (figs. 13 and 14). The average oxygen content in sealed liners for these tests was 10.7 percent. The differences from year to year are believed to be due to differences in film permeability and to fruit variability.

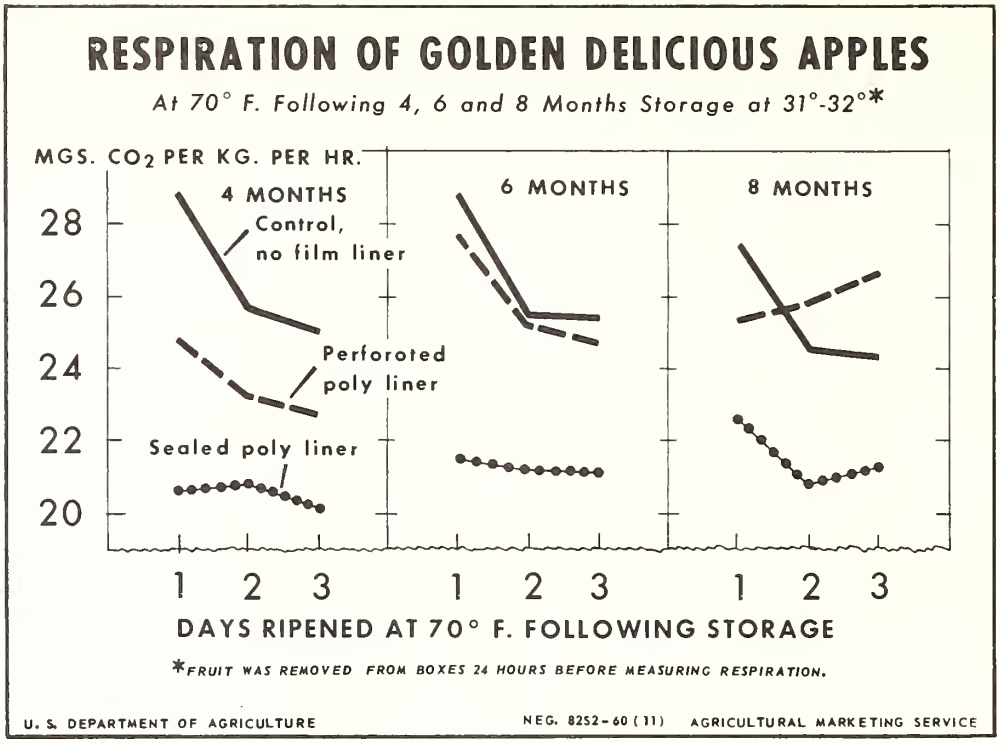

Figure 12

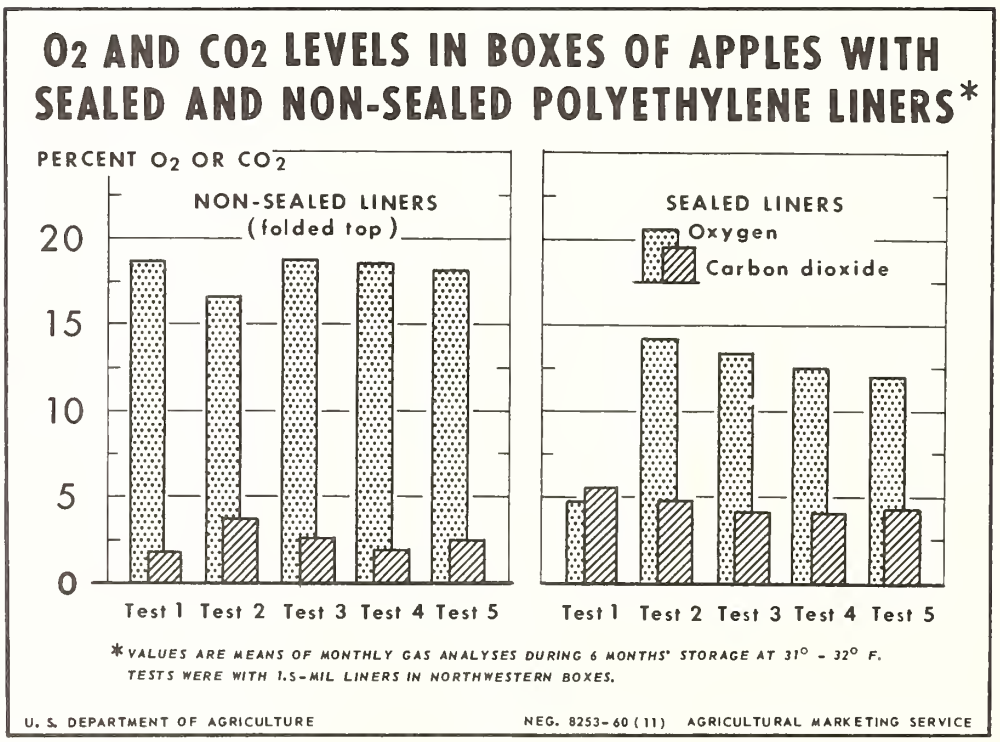

Figure 13

Non-sealed polyethylene liners are already in wide use for Golden Delicious packed in tray- or cell-type corrugated boxes. When a tray or pad is placed over the folded film liner after filling, a fairly tight closure is obtained, resulting in higher carbon dioxide levels than is obtained in non-sealed liners used in wood boxes. Figure 15 shows that with a tray-pack and non-sealed liner, the carbon dioxide concentration was 6 percent during the first 2 months and then dropped to 4 to 5 percent later. With sealed liners in tray-packed boxes, carbon dioxide was 8 percent after one month in storage and then gradually dropped to 5 to 6 percent. The apples were not harmed by these levels of carbon dioxide.

A gas analysis record during storage is shown in figure 16 for three types of sealed polyethylene packs and a perforated pack. Carbon dioxide accumulated in the sealed liners to an equilibrium level of 5 to 6 percent in the first 2 or 3 days in storage. Oxygen dropped to 8 to 10 percent in the first few days after packing and remained within a range of 8 to 13 percent during storage. Some of the irregularity in oxygen concentrations shown in figure 16 is due to analyzing different boxes at various intervals. However, this points out the variability in oxygen levels that one can expect with sealed film liners.

Atmosphere After Removal From Storage. --When apples are removed from cold storage to warmer temperatures during marketing, the respiration rates increase. If apples are in sealed film liners when transferred to warmer temperatures, the atmosphere surrounding the fruit soon is markedly altered. In boxes of Golden Delicious apples with sealed polyethylene liners held 6 days at 70° F. following storage at 31°, oxygen was depleted to an average of 1.5 percent with many boxes having less than 1 percent. Carbon dioxide averaged 10 percent in these sealed box liners. These abnormal atmospheres caused some apples to be off flavored or slightly fermented as mentioned in another section of this report. Sealed polyethylene liners, if used, should be slit open or be removed when taken from cold storage for marketing to avoid this possible harmful effect at warm temperatures. When apples in non-sealed liners were held 6 days at 70° following 6 months in cold storage, the oxygen content of the atmosphere dropped to 5 to 10 percent and carbon dioxide averaged about 10 percent. This indicates that even in non-sealed film liners gas exchange is markedly restricted at room temperature. Therefore, slitting the liner before marketing is desirable even for non-sealed or perforated liners.

Effect of Film Thickness and Density. --Polyethylene films of the same thickness or gage may differ in their permeability to oxygen, carbon dioxide, and other gases. This is usually due to differences in density of the resins used by manufacturers. Low-density polyethylenes are more permeable than medium- or high-density types of polyethylene. As considerable permeability is required in a packaging material for living produce, only low-density polyethylenes (0.914 to 0.928) were tested.

A 1.5-mil polyethylene film with a low density of 0.914 was more permeable to oxygen than one with a density of 0.928. When a 0.928- density film was used, the oxygen in sealed liners sometimes dropped to one percent and the fruit was injured. The average oxygen and carbon dioxide levels maintained in several types of sealed liners during storage is given in figure 17. This shows that different types of polyethylene of the same thickness can maintain different levels of oxygen and carbon dioxide.

Figure 17 also shows that factors other than film density influence the equilibrium concentration of the atmosphere in liners. In the test illustrated, a 0.923-density polyethylene maintained a higher oxygen level (10 to 11 percent) than a 0.919-density polyethylene (6 to 8 percent). This is assumed to be due to slight variations in film thickness (thin spots, pinholes) and to sampling error (triplicate boxes analyzed). Variation of oxygen levels maintained within sealed polyethylene liners of a single type was even greater than variation due to film density. This was true at least for the conventional low-density types of polyethylene tested. The 1.5-mil 0.920-density film (DFDB-0111) maintained a beneficial modified atmosphere averaging 3 to 5 percent oxygen and 5 to 6 percent carbon dioxide. However, variations from the mean for oxygen could make the use of this film as a sealed liner for apples dangerous.

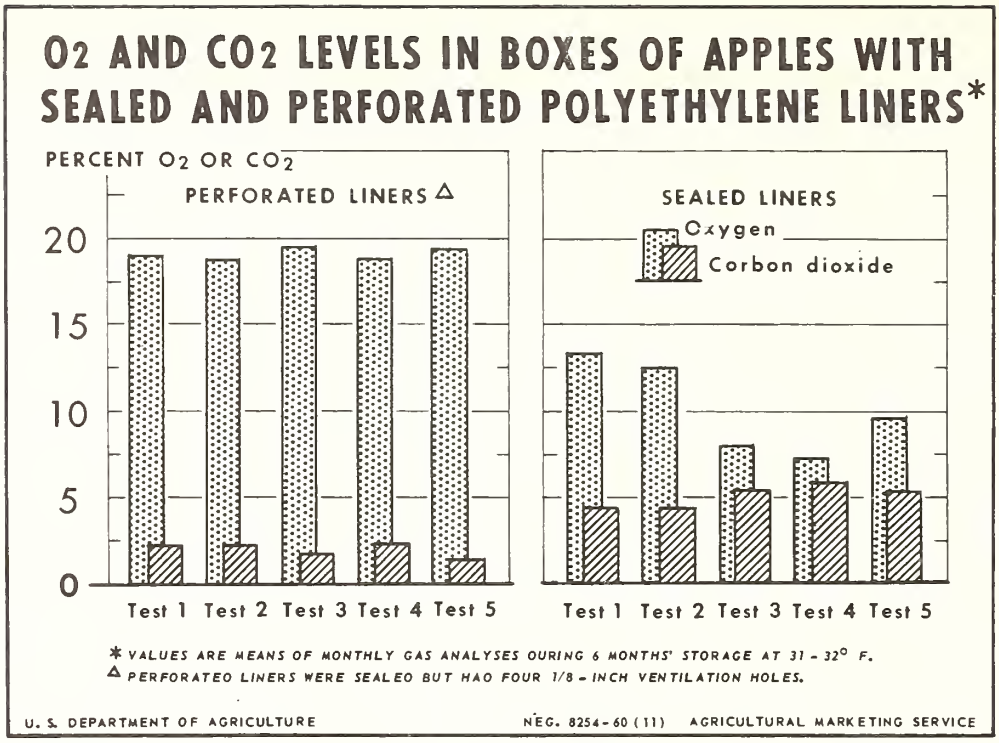

Figure 14

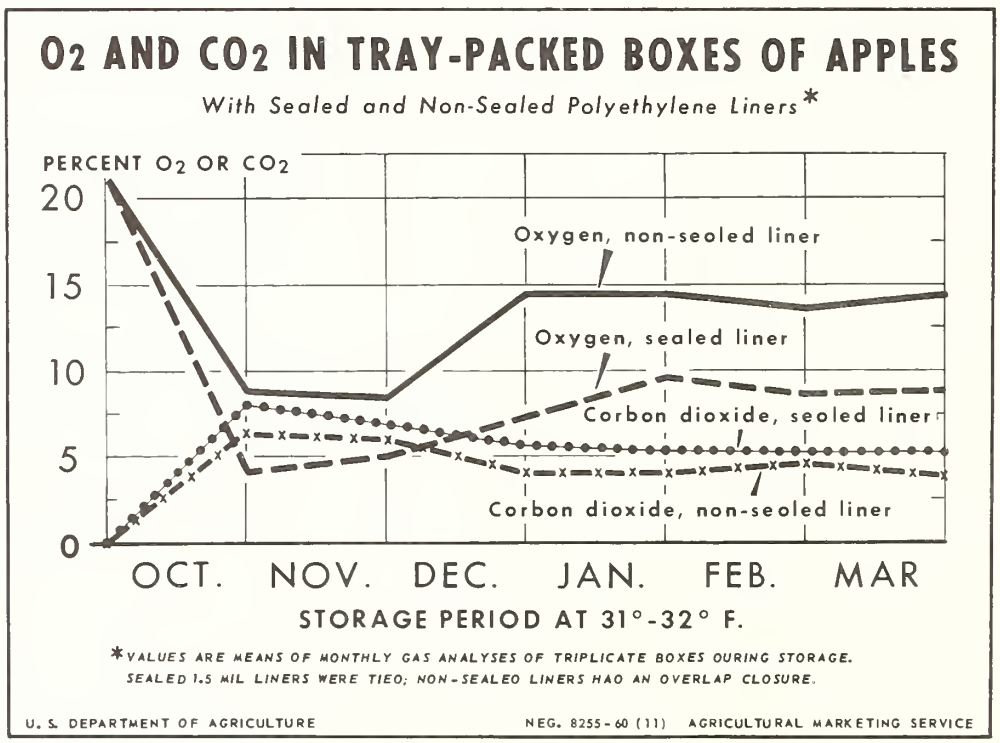

Figure 15

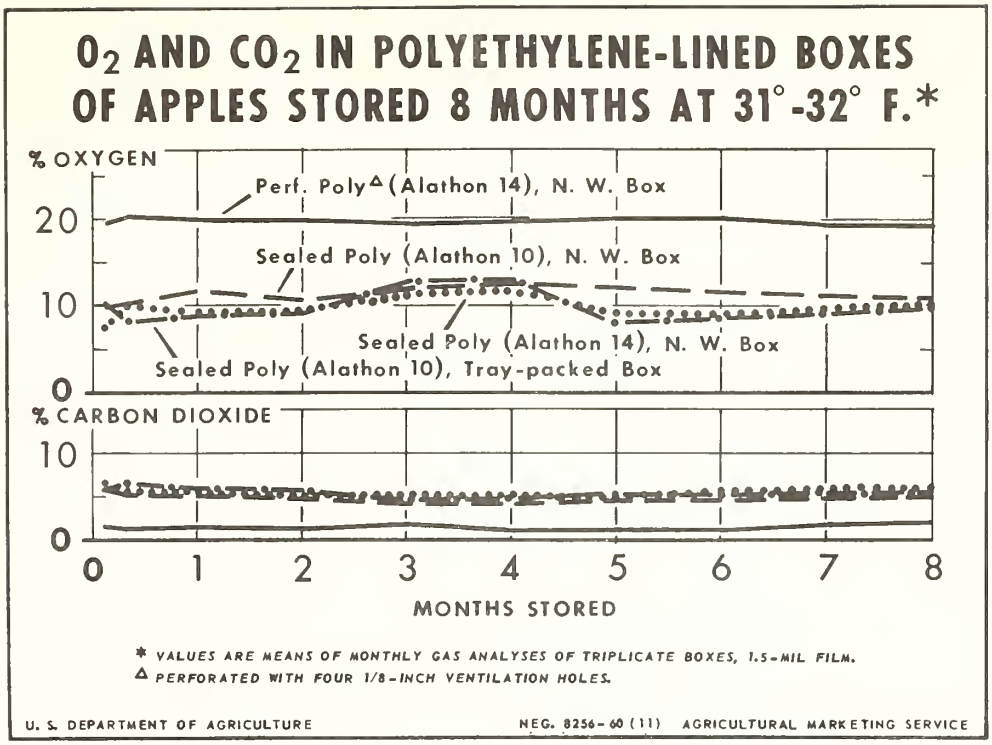

Figure 16

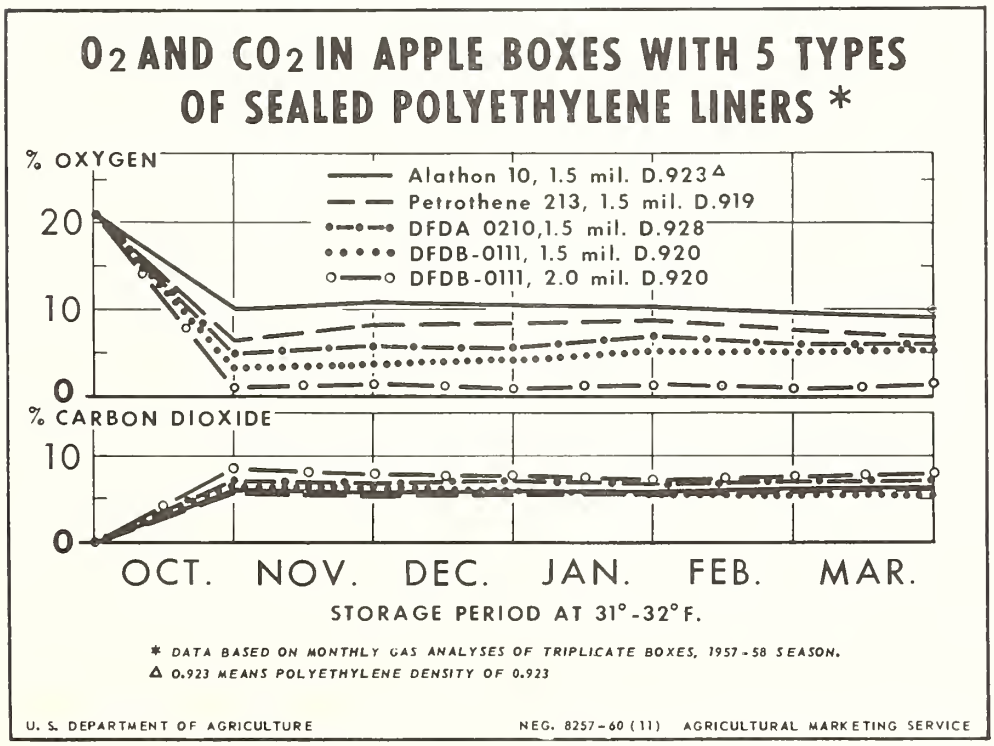

Figure 17

Polyethylene liners made of 2.0-mil film lacked sufficient permeability to be used as sealed liners for storing apples. Golden Delicious apples packed in sealed 2.0-mil liners and stored at 31° to 32° F. maintained box atmospheres of 1 percent or less oxygen and 7 to 8 percent carbon dioxide (fig. 17). When examined after 6 months' storage, this fruit was severely suffocated. It had a fermented flavor and some boxes showed a high percentage of visible injury from the combination of low oxygen and high carbon dioxide concentrations. The injury appeared as a browning of the skin and flesh. In most apples this browning was most conspicuous externally in the calyx cavity (fig. 18). Carbon dioxide concentrations as high as 12 to 15 percent in sealed 2.0-mil polyethylene liners were found in tests with some apple varieties.

Effect of Film Liner Variability.--Sealed polyethylene liners of the same thickness, density, and lot number did not produce a uniform oxygen atmosphere around the fruit. This was true even when the same number and size apples were inclosed. The variation in atmospheres obtained apparently is due to differences in liners; such as thin spots in the film, pinholes, leakage at seams and seals; as well as to slight differences in fruit maturity.

Carbon dioxide in sealed 1.5-mil liners was maintained within a narrow range of 4 to 6 percent. The oxygen level was much more variable, ranging from 4 to 14 percent. This is in agreement with the findings of Ryall and Uota (23) with Yellow Newtown apples. Gas analyses of 25 boxes of Golden Delicious and 25 boxes of Red Rome apples with sealed polyethylene liners are shown in figure 19. This illustrates the wide range of oxygen levels and the narrow range of carbon dioxide levels that can be expected with sealed film liners for commercially packed apples.

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Figure 18.--Suffocation injury resulting from use of 2.0-mil sealed polyethylene boxliners (thicker than recommended) during 6 months' storage at 31° to 32° F. Oxygen levels were maintained at 1 percent or less and carbon dioxide accumulated to 7 to 8 percent.

Figure 20 shows the results of monthly gas analyses of 25 tray-packed corrugated boxes of Golden Delicious apples with non-sealed polyethylene liners. As with sealed liners, a wide range of oxygen concentrations was found, but the average oxygen concentration was much higher. At the first analysis after 1 month's storage, oxygen levels were lower and carbon dioxide levels were higher than at later examinations.

Effect of Fruit Variability. --Several tests in 1955-59 were conducted using the same type of 1.5-mil polyethylene box liners each year. These were made from "Alathon 10," a conventional low-density (0.923) polyethylene resin. Seven different lots of Golden Delicious apples were stored in this film. The results of monthly analyses for oxygen in these sealed liners are given in figure 21. It is obvious that different lots of apples produced widely differing concentrations of oxygen surrounding the fruit. Even though the same type of polyethylene film was used, the oxygen level with different lots of apples ranged from 4 to 12 percent after one month's storage and from 8 to 15 percent after 6 months' storage.

Effect of Fruit Size. --The atmosphere in 20 boxes each of 4 sizes of Golden Delicious apples (72's, 88's, 113's, and 125's), all with film liners, was analyzed after 4 months in storage. This fruit was commercially packed in telescope-type tray-packed corrugated boxes with non-sealed (folded top) 1.5-mil polyethylene liners. The oxygen and carbon dioxide concentrations found are given in table 6. The average oxygen concentration for the different sizes ranged from 13.1 to 16.0 percent and for carbon dioxide from 3.3 to 4.2 percent. Size of apples in standard apple boxes appeared to have no marked effect on the atmosphere that developed within film liners.

Table 6.--Variation in oxygen and carbon dioxide in non-sealed polyethylene-lined boxes containing Golden Delicious apples of different sizes, after 4 months of storage at 31° to 32° F.[1]

	Oxygen (percent)				Carbon dioxide (percent)			
Box number	Size 72	Size 88	Size 113	Size 125	Size 72	Size 88	Size 113	Size 125
1	9.3	9.3	8.0	11.3	5.1	5.5	4.9	4.5
2	10.9	9.8	9.0	11.5	4.9	5.6	5.5	4.4
3	11.4	10.0	9.9	11.8	4.6	5.2	4.8	4.6
4	12.7	10.3	10.2	13.3	3.7	5.0	4.4	4.2
5	13.0	10.8	12.1	13.5	4.9	4.1	3.8	3.6
6	13.4	12.1	12.1	15.1	4.7	3.3	4.8	4.2
7	14.1	12.3	12.5	15.1	4.2	3.3	4.6	3.5
8	14.2	13.2	12.9	15.7	3.9	4.0	4.1	3.6
9	14.2	13.8	13.0	16.2	4.5	4.0	4.6	3.2
10	14.5	14.5	13.0	16.5	4.0	2.7	4.0	3.5
11	15.0	15.2	14.0	16.6	4.1	3.3	4.0	2.7
12	15.0	15.3	14.0	17.0	4.1	3.5	4.0	3.3
13	16.0	15.7	14.1	17.5	3.7	3.1	3.0	3.0
14	16.3	16.0	14.1	17.7	3.0	2.7	4.4	2.6
15	16.9	16.4	14.4	17.7	3.0	3.9	4.5	3.3
16	17.0	16.7	14.5	18.2	3.5	3.2	4.0	2.6
17	17.5	17.1	14.5	18.4	3.6	2.3	3.0	2.2
18	17.6	18.0	15.8	18.5	3.4	2.4	3.8	2.8
19	19.0	18.1	16.6	18.9	1.8	2.5	2.8	2.5
20	19.7	18.2	16.6	19.6	1.5	2.4	4.1	1.8
Mean and std. error of mean.	14.9±.6	14.1±.7	13.1±.5	16.0±.6	3.8±.2	3.6±.2	4.2±.2	3.3±.2

[1] Commercially packed apples in corrugated tray-pack boxes with non-sealed (folded-top) 1.5-mil polyethylene liners, 1958-59 season.

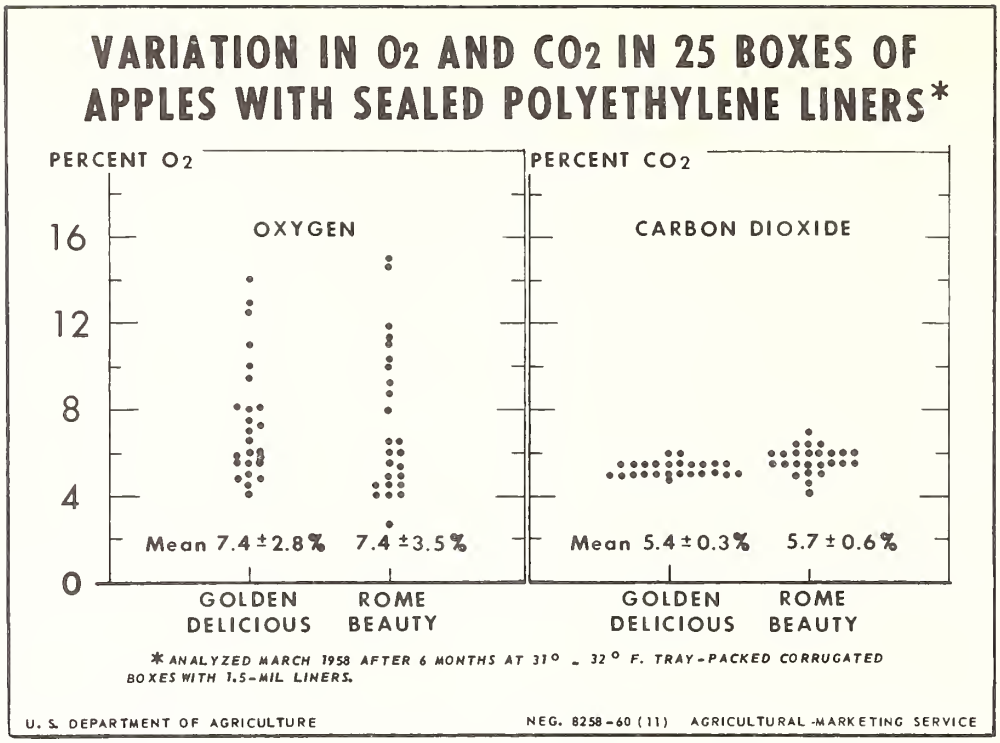

Figure 19

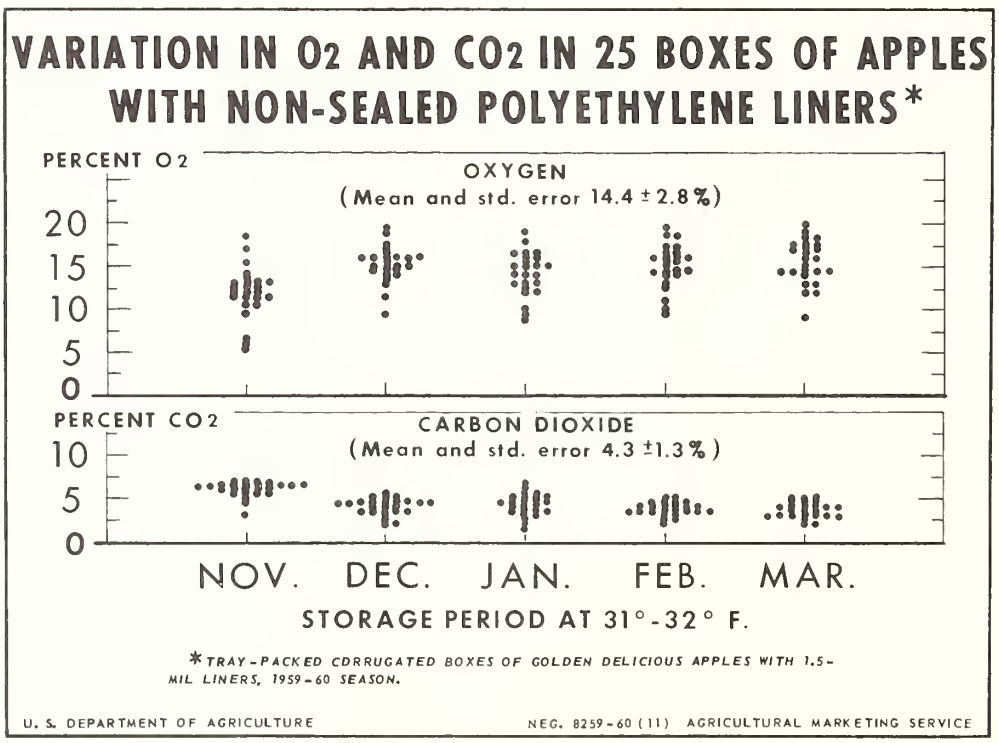

Figure 20

Effect of Initial Fruit Temperatures. --Golden Delicious apples were stored at several different temperatures for 2 days and then packed and sealed in polyethylene liners before storage at 31° to 32° F. This gave initial fruit temperatures of 79°, 62°, 44°, and 34° for samples of the same lot of fruit. The atmosphere in the sealed liners was analyzed after 4, 7, and 14 days and at monthly intervals during storage (fig. 22). The greatly differing initial fruit temperatures did not influence the equilibrium concentrations of oxygen and carbon dioxide. This was particularly true for carbon dioxide, which was maintained within a narrow range regardless of initial fruit temperature. This is in agreement with the findings of Workman (30). Carbon dioxide reached a peak of about 7 percent 2 weeks after storing and thereafter declined to about 5 percent in 3 to 6 months.

Oxygen levels, while somewhat more variable than carbon dioxide, were not markedly different as a result of the different initial temperatures. Oxygen ranged from 10 to 14 percent during most of the storage period. It reached the lowest levels within the first 2 to 4 weeks of storage. Warm fruit did not lower the oxygen level faster than cool fruit during the first week in sealed liners, even though it would be expected that the warm fruit would use oxygen more rapidly and perhaps deplete the inclosed supply of oxygen faster than it could enter by diffusion through the film. Apples packed in sealed film liners with too high initial temperature could be injured if the oxygen should drop below 2 percent.

Some precooling of apples before packing in either sealed or non-sealed polyethylene liners would be advisable to prevent possible damage from over depletion of oxygen in the atmosphere. In most of the tests described in this report, apples were packed warm (70° F.) without precooling and none were injured. However, in commercial practice where whole pallet loads of apples in film might be packed warm and stacked together, cooling would be slower and the possible danger greater.

Effect of Initial Atmosphere. --Air is sometimes partially removed from film-lined boxes of apples with a vacuum hose before the top is folded or tied. This draws the film tightly around the fruit, helping to give a good-looking pack without slack. It also eliminates film pillowing, which hinders closing or sealing, and prevents film punctures during lidding. This partial evacuation of the air had no appreciable effect on the atmosphere maintained within sealed liners during storage (table 7).

The possibility of adding nitrogen to lower the oxygen concentration to 5 percent before sealing the liners was investigated. In another treatment, 10 percent carbon dioxide was added to film-lined boxes before sealing. Table 7 shows the atmospheres maintained within these liners over a 6 months' period. Polyethylene film (1.5-mil) was too permeable to maintain these atmospheres at the initial level. In 7 to 14 days after sealing the carbon dioxide and oxygen concentrations were at the equilibrium levels maintained in control liners without added nitrogen or carbon dioxide. The quality of the apples after 6 months' storage in the sealed liners with different initial atmospheres was still good. Initial addition of carbon dioxide or nitrogen to each box did not improve quality maintenance or lengthen storage life. Fruit firmness, decay, and condition were similar in the various treatments.

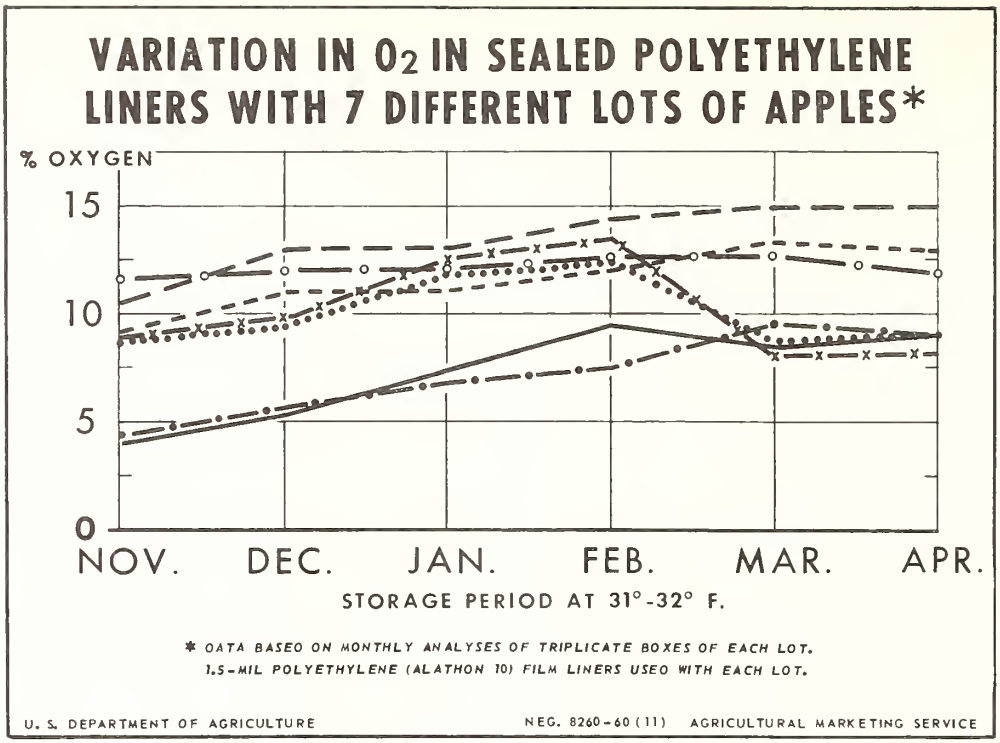

Figure 21

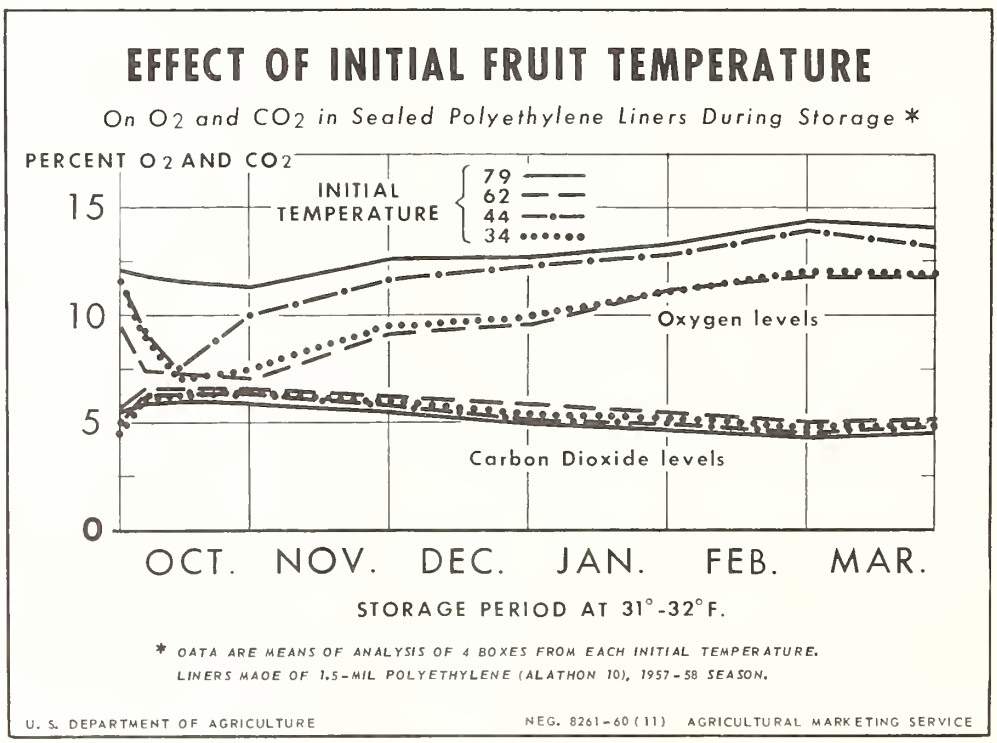

Figure 22

Table 7.--Effect of initial air evacuation and addition of nitrogen or carbon dioxide on the carbon dioxide and oxygen levels maintained in sealed polyethylene-lined boxes of Golden Delicious during storage at 32° F.[1]

Storage period	Carbon dioxide (percent)				Oxygen (percent)			
	Control, No treatment	Air evacuated initially	95% N_2 initially	10% CO_2 initially	Control, No treatment	Air evacuated initially	95% N_2 initially	10% CO_2 initially
4 days	5.8	6.5	5.5	13.2	9.1	6.9	8.4	6.1
7 days	6.7	6.5	6.9	9.9	7.7	7.2	9.1	7.5
14 days	6.7	6.6	6.0	7.5	7.5	8.2	10.7	9.4
1 month	6.4	6.4	5.6	6.8	10.6	9.6	11.9	11.0
2 months	5.7	6.1	5.6	6.0	13.1	10.9	12.5	12.5
3 months	5.1	5.6	5.2	5.5	13.0	10.7	12.9	12.2
4 months	4.9	5.2	5.1	5.0	14.3	12.1	13.6	14.2
5 months	4.4	4.7	4.3	4.4	14.9	12.9	14.4	15.2
6 months	4.5	5.0	4.9	4.7	14.9	13.0	13.7	14.5
Mean	5.6	5.8	5.5	7.0	11.7	10.2	11.9	11.4

[1] Data based on analyses of quadruplicate boxes, 1957-58 season. Sealed polyethylene liners were made of 1.5-mil Alathon 10. Initial fruit temperature 65° F.

DISCUSSION AND CONCLUSIONS

Polyethylene box liners may be used in several types of storage containers for Golden Delicious apples. They may be inserted in field crates either in the orchard or after sorting. They may be used in standard wood or corrugated storage and shipping boxes. Probably the commonest use is as a liner in cell-type or tray-pack corrugated boxes. Large polyethylene liners can be used in bulk boxes or pallet boxes holding 20 or more bushels. Polyethylene pallet covers can be used to cover even larger quantities of fruit. In this case, the film is not a box liner, but serves as a moisture-vapor barrier outside the boxes.

Only good quality, sound fruit from clean orchards should be stored in polyethylene-lined containers, because the high relative humidity maintained within a film liner is favorable for decay development. Film liners should be considered only for that portion of a crop intended for long storage, as regular high-humidity refrigerated storage will maintain quality of Golden Delicious for 3 to 4 months. Fruit firmness at harvest should be 14 to 17 pounds. If fruit is too mature for long storage, the possible benefits from polyethylene liners cannot be obtained. Such fruit may eventually split or crack open in film.

The main advantage of film liners for Golden Delicious apples is prevention of moisture loss and shriveling. Relative humidity is maintained at a very high level within the moistureproof liners. Moisture loss from apples is most rapid in the weeks immediately following storage, so fruit should be protected during that period. Non-sealed (folded-top) or perforated polyethylene liners are as good as sealed liners for preventing this moisture loss. If a sealed film liner is used or the film closure is tight enough to allow a build-up of carbon dioxide and a marked reduction of oxygen, a beneficial atmosphere is obtained. The rate of metabolism is then reduced as evidenced by reduced respiration, slower softening, and slower development of yellow color. The combination of high humidity to prevent shriveling and a modified atmosphere to retard ripening can increase the storage life of Golden Delicious apples. A somewhat longer shelf life is also possible as a residual effect of packing this variety in polyethylene.

Premium prices received for good quality Golden Delicious apples late in the storage season should repay the cost of the film liners (8 to 12 cents each) several times.

Non-sealed liners with overlap fold are in widest use commercially. They provide most of the advantage given by a sealed liner with fewer hazards. However, in the experiments discussed in this report, sealed liners almost always maintained quality better than non-sealed liners in 31° to 32° F. storage. Storage-house managers desiring to try sealed polyethylene liners should do so only on a small scale at first. They should be convinced from their own experience that desired improvements in quality maintenance can be obtained. They should be aware that many types of polyethylene are now available and be as specific as possible in ordering liners, especially if they have had previous experience with a certain type.

Schomer, Gerhardt, and Sainsbury (25) showed that film liners have some restrictive effect on rate of fruit cooling. However, when fruit had been in storage long enough to reach a stable temperature, the temperature of poly-packed fruit was only a fraction of a degree higher than that of fruit in unlined boxes. In commercial practice, many apples are precooled in field containers before repacking into polyethylene-lined cell or tray-pack cartons. This procedure minimizes any restrictive effect of film liners on fruit cooling rate.

Careful control of storage temperature is essential for successful use of polyethylene liners. All the work conducted by the authors was at a storage temperature of 31° to 32° F. which is optimum for late storage of Golden Delicious apples. At higher storage temperatures with more rapid fruit respiration, it might be expected that equilibrium levels of oxygen might be lower and carbon dioxide levels higher within sealed liners. Injury may develop if the oxygen drops below 2 percent and carbon dioxide accumulates above 7 to 8 percent.

Polyethylene liners, whether sealed, perforated, or non-sealed, should be removed or slit open when fruit is taken from storage for marketing. This will prevent harmful effects from inadequate gas exchange owing to more rapid respiration of fruit at higher temperatures found in marketing channels. Fruit flavor can be damaged in a short time at warm temperatures if polyethylene liners are not opened.

The benefits of sealed liners may be lost by holes in the liner from rough box surfaces or staples, or a leaking seam or closure may prevent formation of a proper atmosphere. If a sealed liner is damaged or not sealed properly, only the benefits of perforated liners--prevention of weight loss and shriveling--could be obtained from it.

Many types of polyethylene film are available from different sources, produced by different manufacturing processes, from various density resins, and of various thicknesses. Recommended film is 1.5 mils thick. Films 2.0 mils thick used as sealed liners may suffocate fruit. Conventional low-density (0.925 or under) polyethylene was satisfactory in these tests. Medium- or high-density polyethylene films used as sealed liners have inadequate permeability for apples.

Variations in film thickness caused greater differences in box liner atmosphere than did variations of film density. In some tests in which 1.6- or 1.7-mil film was received instead of specified 1.5-mil film, fruit was injured during storage even though the film was a low-density type. Commercially extruded polyethylene of more uniform gage is needed. A narrow tolerance on film gage should help advance new uses of film for fruit storage, especially where use of a sealed liner is contemplated.

The atmospheres developing within 1.5-mil polyethylene-lined apple boxes are predictable only within a range. In a field crate or loose-packed box with a non-sealed (folded top) liner, 17 to 20 percent oxygen and 1 to 4 percent carbon dioxide are typical. In a telescope-type corrugated box with tray-packed fruit and non-sealed liners, 8 to 15 percent oxygen and 4 to 6 percent carbon dioxide are typical. Sealed polyethylene liners which were perforated with four 1/8-inch holes to provide some ventilation, provided atmospheres of 19 to 20 percent oxygen and 1 to 2 percent carbon dioxide. The atmosphere that develops in sealed polyethylene-lined boxes of Golden Delicious apples is difficult to predict. Oxygen levels from 4 to 15 percent and carbon dioxide levels from

4 to 8 percent were found in various tests. In general, these modified atmospheres had a beneficial effect on quality maintenance.

The modified atmospheres obtained in commercial controlled-atmosphere (C-A) storage and in sealed film box liners are quite different. For maximum benefits from C-A storage, levels of about 3 percent oxygen and 3 percent carbon dioxide are recommended for Golden Delicious apples. On the other hand, the oxygen level in 1.5-mil polyethylene liners is usually higher than the optimum 3 percent, and the atmosphere is uncontrolled and cannot be adjusted as it can in a C-A storage room. Polyethylene liners can be relied on to prevent weight loss and shriveling, but they cannot be expected to extend storage life of apples as long as will a good C-A storage.

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