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CHANGES IN LEMONS DURING STORAGE AS AFFECTED BY AIR CIRCULATION AND  
HARVEY, E. M. 1 OF 1

A resolution test chart featuring various patterns of vertical and horizontal lines. The patterns are arranged in a grid-like fashion, with numerical values indicating the resolution level. The values include 1.0, 1.1, 1.25, 1.4, 1.6, 1.8, 2.0, 2.2, 2.5, 2.8, 3.2, 3.6, 4.0, and 4.5. The lines become progressively thinner and closer together as the numerical value increases.

MICROCOPY RESOLUTION TEST CHART  
NATIONAL BUREAU OF STANDARDS-1963-A



**UNITED STATES  
DEPARTMENT OF AGRICULTURE  
WASHINGTON, D. C.**

# Changes in Lemons During Storage as Affected by Air Circulation and Ventilation<sup>1</sup>

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## HANDLING THE COMMERCIAL CROP OF LEMONS

The commercial lemon-growing industry of the United States is centered largely in California, where the annual fresh-fruit production averages upwards of 14 million packed boxes, or about 30,000 carloads, of which about 4.5 percent went to the armed forces during the war. These figures do not take into account the lemons used for byproducts, amounting to 15 percent or more of the total production. The bulk of the lemon byproducts is used by the armed forces.

The lemon tree blooms more or less continuously, and mature fruit as well as blossoms occurs on the tree every month of the year; however, the heaviest bloom occurs in March or April, so that most of the fruit is ready for harvest in winter and spring. The greatest market demand for lemons, however, is from June through August. This demand is met by storing most of the winter- and spring-harvested fruit at the place of production. The fruit is sorted, washed, sometimes treated with a water-wax emulsion, and held loose in boxes in rooms equipped with ventilating or air-conditioning devices to maintain the desired

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storage condition. The average storage period for the lemon crop as a whole is about 3 months; such storage costs about 11 cents per box, or about 1 percent of the 1943 retail price. When the time for shipment arrives the lemons are graded, sized, and packed in boxes as they are usually seen on the market. Lemons may also be stored temporarily after receipt in terminal markets, but the investigations reported in this bulletin are concerned altogether with the storage of loose fruit in the producing area. The storage of packed fruit after arrival in terminal markets involves additional problems that are not covered.

### IMPROVING THE KEEPING QUALITY OF STORED LEMONS

The cost of holding lemons in storage is increased by the practice of altering the temperature and moisture content of outside air introduced in sufficient quantities to keep the carbon dioxide content below 0.5 percent. This limit was evidently set rather arbitrarily from the results of experiments on degreening, or coloring, of citrus fruit with ethylene, which showed that more than a few tenths of 1 percent of carbon dioxide retarded the coloring process. It would be supposed that factors which favor rapid coloring would be likely to favor ripening and those which tend to retard coloring and ripening might be expected to favor longer storage of fruit through the retardation of vital processes. While it is highly improbable that even much larger accumulation of carbon dioxide in itself would be injurious to stored lemons, the problem is complicated because other substances (emanations) are given off by fruit in storage and some of these less abundant products may be far more injurious than carbon dioxide. Under such conditions a very small limitation set as a permissible accumulation of carbon dioxide becomes a practicable and easily determinable indirect index of the presence of the more harmful products that cannot be determined directly.

Direct evidence of the production of other gases by citrus fruit was obtained by Miller, Winston, and Fisher (7)<sup>3</sup> and Biale (8). These writers showed that decaying and even normal citrus fruit may produce emanations, presumably ethylene, which cause epinasty in tomato, potato, and other growing plants and accelerate respiration and degreening in lemons. Their findings indicated that the relative value of ventilation (introduction of rather large quantities of fresh, conditioned air as in commercial storage) and air circulation in storage of lemons should be rechecked.

The problem claims further attention because of the growing suspicion, supported by evidence of plant indicators, that the "fresh air" around lemon storage basements located near busy streets and highways may carry a sufficient admixture of automobile exhaust gases to be harmful; for example, it is not uncommon to see trucks with motors running standing with exhausts directed toward the fresh-air intakes of lemon storage rooms in the basement of packing plants. If the increasing amounts of automobile exhaust gases in the environment prove to be a serious factor, it will be necessary to devise methods for chemically freeing the introduced fresh air from carbon monoxide, ethylene, and other unsaturated hydrocarbon gases in addition to the present air conditioning. There is a possibility too that certain gases, such as are now being introduced into lemon storages as disinfectants (8), may also prove capable of destroying *in situ* the injurious emanations of fruit and molds and the harmful constituents of automobile exhausts.

<sup>3</sup> *Italic numbers in parentheses refer to Literature Cited, p. 32.*

Such considerations are likely to keep open the question of the amount and kind of ventilation necessary for lemons in storage.

From 1938 to 1941 Eureka lemons, the most common variety grown in California, were studied to determine the physiological changes that occur during long periods of storage, the correlation between such changes, their relation to alternaria rot, and the relative effects of ventilation, air circulation, and still air on such changes and the keeping quality of lemons.

The study showed in general (1) that air circulation cannot be substituted for ventilation as ordinarily provided in commercial storage; (2) that sufficient carbon dioxide does not accumulate in commercial storage to injure lemons, but it did not eliminate the probability that certain other emanations (particularly ethylene) of molds and of the lemons themselves can easily become injurious to lemons held in long storage; and (3) that the percentage of buttons that are green and their rate of change from one color class to another afford a practical means of predicting the maximum safe period for holding a given lot of lemons in storage. Suggestions are made for collecting and arranging data for index purposes (p. 25). The results of the tests are summarized in more detail as follows:

Weekly loss of weight was greatest in the commercial storage (control) and least in the still-air chamber. Lemons of different stages of maturity lost weight in the following order: Tree-ripe, silver, light-green, and dark-green. The differences in rate of weight loss for all practical purposes was negligible, because of differences in the relative durations of storage of fruit of different maturities. Lowering the relative humidity in storage 5 percent without changing the temperature more than doubled the rate of shrinkage of lemons for about 3 weeks afterward.

In commercial storage (control) the carbon dioxide content was less than 0.1 percent. In 1938 the average maximum carbon dioxide accumulation was generally greater in the circulating-air chamber than in the still-air one, but in 1939 the reverse was true; in 1940 the accumulation was greater in the circulating-air chamber than in the ventilated one. The total extractable volumes of internal gases of lemons varied with the maturity in the following decreasing order: Silver, tree-ripe, light-green, and dark-green. High volume yields were associated with high oxygen and low carbon dioxide and vice versa. The average carbon dioxide content of lemons was greatest in the still-air chamber and least in the circulating-air one.

The first external sign of alternaria decay was seldom found to indicate decay in more than 1 percent of the other lemons. When at least 2 percent of the lemons showed externally visible symptoms of decay the lot was considered to have reached decay break (beginning of definite susceptibility to *Alternaria*). This later was arbitrarily fixed at 3 percent. The length of time lemons could be held in storage before decay break occurred depended upon their stage of maturity at storage, the time of picking, the year, and the condition of storage; but the rate of subsequent decay was rapid and rather uniform regardless of the original storage quality. At or near decay break lemons changed from almost complete immunity to *Alternaria* to extreme susceptibility. The order of increasing keeping quality of fruit picked on the same date was in general tree-ripe, silver, light-green, and dark-green. Lemons picked in midwinter had the best storage qualities; after February their keeping quality diminished until late spring and

early summer. Light-green lemons picked in February did not reach their decay break until 6 weeks after those picked from the same grove in May. Fruits keep much longer in storage in some years than in others. Decay developed earlier in the still-air chamber than in the circulating-air one and earlier in the latter than in commercial storage.

The residue-solids ratio of lemons, as determined by a method described (p. 15), decreased rather steadily to a minimum near the close of the storage period and then increased slightly. Thus, there was indicated a corresponding change in the solubilities of the wall substances. The ratios also differed greatly with stage of maturity of the fruit.

Buttons of stored lemons were classified in five categories (full-green, intergreen, interblack, full-black, and off), described on page 19. The changes in button conditions were related to time of picking, stage of maturity, and condition of storage.

Close correlation was observed between the condition of buttons and the development of alternaria decay, often many weeks later. A possible practical method of predicting the maximum safe storage period for any given lot of lemons, particularly silver and tree-ripe ones, by several inspections of the button condition and comparison with standards is described on page 19. The behavior of tree-ripe lemons often could be predicted from an initial inspection and another about 3 weeks after storage, of silver from two or three inspections during a storage of 8 to 10 weeks, and of light-green only after one more inspection and a longer period of storage.

Special respiration tests indicated that during storage the potential anaerobic responses of lemons continually change. Immediately after being placed in storage their potential for anaerobic respiration increases for usually a few weeks; afterward it decreases steadily to the end of the storage life of the lemon. The decay break appears to come just previous to what may be called the storage climacteric, when the anaerobic responses of the lemon show complete reversal from what they were at the beginning of the storage period.

### MATERIAL AND EQUIPMENT

From 1938 to 1941, inclusive, the storage of Eureka lemons, the most common variety in California, was studied. During 1938 the lemons were from four districts: Corona, Glendora, San Juan Capistrano, and Piru. In subsequent seasons they were, with a few exceptions, from different blocks in the large grove of the American Fruit Growers, Inc., at Corona.

Space was provided by the American Fruit Growers, Inc., in the storage basement of its packing house at Corona. This basement was equipped with one of the most modern types of apparatus for the control of temperature, relative humidity, and ventilation. During the early part of 1938 (to May 18) a temperature near 56° F. and a relative humidity of 90 to 93 percent were maintained. Later the temperature was kept the same, but the relative humidity was lowered to 85 to 88 percent, or about 5 percent. The amount of fresh outside air introduced into the circulating system was so regulated that at no time was the carbon dioxide accumulation found to exceed 0.1 percent. This commercial storage provided the control condition in the various experiments.

Two experimental chambers were built in the storage basement just mentioned. They measured 8 by 8 by 7 feet and were constructed of

three-ply boards on two-by-fours. The doors were tightly fitted, and all joints of the walls and ceiling were sealed with a waterproof linoleum paste. The temperature within these chambers was the same as that of the general storage outside except that the slight fluctuations occurring outside were not noticeably transmitted into the chambers. The relative humidity was usually slightly higher within the chambers than outside. The increase in relative humidity was difficult to measure but could be safely assumed to be 1 to 2 percent. Each chamber was provided with copper-tubing outlets to allow gas sampling without the necessity of opening the doors. One of the chambers was used for testing the effect of air circulation; the other was maintained until 1940 (p. 7) without either ventilation or air circulation except that due to infrequent opening of the door to put in or take out fruit, in order to compare a storage known to be unfavorable with others thought to be favorable.

The analysis of carbon dioxide and oxygen was made with a somewhat modified Haldane-Henderson apparatus, and the extraction of the internal gas of lemons was done with a specially constructed apparatus described by Brooks (3). The extracted gases were collected for analysis in 250-ml. gas-sample tubes.

The respiration studies were of the special anaerobic type described by Harvey and Rygg (5). Most of the results were obtained with the apparatus mentioned by them, but in 1941 the 1-gallon mayonnaise jars were replaced by 2-gallon metal containers having specially constructed rims and lids. This type of chamber not only increased the size of the sample but simplified greatly the operation and removed the danger of violent breakage.

The details of other methods and procedures employed are found in the sections presenting the results.

## COMPARISON OF STILL-AIR, CIRCULATING-AIR, AND COMMERCIAL STORAGES

### LOSS OF WEIGHT IN LEMONS

Some loss of weight, or curing,<sup>1</sup> of lemons is generally accepted as desirable, for it decreases the risk of injury in subsequent handling operations and consequently lessens the danger of fungus invasions. However, during relatively long storage periods this loss of weight can easily exceed the amount desirable for best curing if the temperature, air circulation, and relative humidity are not controlled within the proper ranges. The more modern plants for lemon storage are undoubtedly meeting these conditions very satisfactorily, so that the only justification in presenting the observed results on the rates of shrinkage of lemons in storage is to show the relative effects of the altered experimental conditions in comparison with those in commercial storage.

A total of 63 boxes of lemons was used in tests to determine the average weekly losses of weight under 3 storage positions (table 1). They represented 3 general picking periods 6 to 7 weeks apart and 4 stages of maturity: Dark-green (9 boxes), light-green (21 boxes), silver (21 boxes), and tree-ripe (12 boxes). All 3 general pickings were made at Corona, the first and second at Glendora, and the first only at San Juan Capistrano and Piru. It is rarely possible to obtain lemons representing all 4 stages of maturity on a single picking date in 1 section of a grove, but under this condition one may often obtain

<sup>1</sup> The term "curing" is sometimes used to include the coloring process also.

3—either dark-green, light-green, and silver or light-green, silver, and tree-ripe; the shift in maturity stages occurs from midwinter to early summer. At each picking period and location 3 stages of maturity were obtained for these tests under the limitation indicated.

The range of losses from the 21 boxes in commercial storage was 0.32 to 1.62 percent per week, the average being 0.83 for the entire storage period (table 1). The 2 experimental storage positions showed slower rates of shrinkage than the commercial; the still-air storage showed the least, as was to be expected. In the various characteristics observed the response of lemons in the circulating-air chamber was always intermediate between those in the still-air and those in the commercial, usually closer to the former.

TABLE 1.—Average loss of weight per week by lemons in storage, 1938

[3 pickings, 4 stages of maturity, and 3 positions of storage at 90 to 93 percent relative humidity before May 18 and 85 to 88 afterward and 56° F.]

Date picked	Date stored	Storage period	Average loss of weight in indicated position of storage			
			Commercial room	Circulating-air chamber	Still-air chamber	Average
		Weeks	Percent	Percent	Percent	Percent
February 28.....	March 2.....	1 10 or 2 14	0.60	0.60	0.49	0.55
April 13.....	April 16.....	4	.87	.71	.46	.68
May 20.....	May 31.....	11	.97	.63	.30	.62
Average.....			.83	.58	.44	.62

1 7 boxes. 2 2 boxes.

The stage of maturity had some influence on the average rate of shrinkage, but the difference did not seem to be significant. Tree-ripe fruit, which is not generally considered storable and is held for only relatively short periods, if at all, gave the highest rate of shrinkage (0.69 percent weekly). The weekly shrinkage rates were 0.60 percent for silver lemons, 0.57 percent for light-green, and 0.52 percent for dark-green. However, since the relative length of the usual holding time increases in the order in which the maturities are named, the differences noted in the rates of shrinkage would be negligible for all practicable purposes.

During 1938 the relative humidity of the commercial storage room had been maintained at 90 to 93 percent until May 18. With this very high humidity molds were able to establish themselves upon the walls, which had received a casein-base paint, and on the softer strips of lumber of the box ends. Because of the suspicion of possible harmful effects of these molds, a series of tests for ethylene in the storage atmosphere was made with tomato, potato, and etiolated sweet pea seedlings as indicators. These tests all proved positive. Therefore, without then knowing whether these emanations were produced by the molds, the fruit itself, or both, it was recommended that the relative humidity be lowered as a means of controlling this mold growth. On May 18 the relative humidity was lowered to 85 to 88 percent, or approximately 5 percent. The molds soon came under control, but in a few days it was noted that the lemons were losing a considerable amount of their previous fresh appearance and luster. This suggested a special check on loss of weight of fruit under the altered relative humidity.

Four boxes of lemons of the first pickings at Corona and Glendora (stored March 2) were selected from the commercial storage and

reweighed on May 23, 5 days after the relative humidity had been lowered 5 percent and 10 days after the last regular weighings. For the 10-week period before May 13 the average loss of weight of these four boxes had been 0.65 percent per week. The 10-day period from May 13 to May 23, including 5 days at the higher relative humidity, showed an average loss of 1.12 percent per week. The next period, May 23 to June 3, showed an average loss of 1.51 percent per week. However, during the last period that this fruit was weighed, June 3 to 17, the rate of loss had fallen to .88 percent per week. The lowering of the relative humidity had apparently allowed more than double the rate of shrinkage of fruit for 3 or more weeks after the change, amounting to the difference between a loss of about 0.3 and a loss of about 0.8 pound per loose box per week in storage.

During 1939 the same experimental conditions were maintained as in the latter part of 1938. Therefore, from the earliest pickings of this season only two boxes in commercial storage were selected for shrinkage determination. These samples were weighed at intervals of 3 to 4 weeks from late February to May 17. The results were in good accord with those obtained in 1938.

With the beginning of the 1940 season the still-air chamber was altered to a ventilated one by making openings through its walls for continuous forced ventilation through the chamber from the main storage room. The main commercial room was maintained through this season at 56.5° to 58° F. and 88 to 90 percent relative humidity, an average temperature about 1° higher and an average relative humidity about 3 percent higher than that of 1939 and the latter part of 1938.

All the lemons used in 1940 were from Corona. At various intervals during the season fruit samples were removed from storage for certain laboratory experiments. Table 2 gives the average loss of weight per week under the three storage conditions. The losses shown for the second period of storage appear too large, as there was no recorded change in the general environment. However, the continual dwindling of the supply of fruit in commercial storage might account for the increase, because of the resulting greater exposure of that fruit to evaporational factors.

TABLE 2.—Average loss of weight per week by lemons in storage, 1940

Storage position	February 14 to April 30	April 30 to May 27
	Percent	Percent
Commercial room.....	0.74	1.13
Ventilated chamber.....	.68	.91
Circulating-air chamber.....	.63	.77
Average.....	.65	.94

## CARBON DIOXIDE AND OXYGEN CONTENTS

### EXTERNAL ATMOSPHERE

The carbon dioxide and oxygen contents of the experimental storage chambers were determined at intervals throughout the season. The samples were always collected immediately before the necessary opening of the doors to put in or take out fruit. In every analysis the air of the commercial storage room showed less than 0.1 percent of carbon dioxide, probably too little to be considered of significance in itself. Examples of the accumulation of carbon dioxide in the experimental

chambers are shown in table 3, in which are given the carbon dioxide maxima and the oxygen minima, selected from analyses made at the end of the longest periods with closed doors in 1938. The average highest accumulation of carbon dioxide for any position was 1.31 percent. It seemed clear that the accumulation of carbon dioxide was prevented by the ventilation resulting from the occasional opening of doors and by leakage through the three-ply board walls of the chambers into the general storage room. This is also indicated by the fact that during 1939 there was one period when the doors remained closed for 21 days, yet the maximum carbon dioxide accumulation was only 1.14 percent in the circulating-air chamber and an average of 1.39 percent in the still-air one (average of top, middle, and bottom portions).

TABLE 3.—Maximum carbon dioxide and minimum oxygen in closed experimental chambers, 1938

Storage position	Carbon dioxide and oxygen, after indicated period (days), <sup>1</sup> on—									
	March 18 (6)		March 25 (10)		April 22 (6)		May 5 (13)		May 25 (8)	
	CO <sub>2</sub>	O <sub>2</sub>	CO <sub>2</sub>	O <sub>2</sub>	CO <sub>2</sub>	O <sub>2</sub>	CO <sub>2</sub>	O <sub>2</sub>	CO <sub>2</sub>	O <sub>2</sub>
Still-air chamber:	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent
Top.....	0.32	20.52	0.40	19.50	0.61	19.02	0.62	20.04	0.37	20.17
Middle.....	.37	20.45	1.12	19.75	.60	19.70	.84	20.04	.64	20.17
Bottom.....	.42	20.42	1.31	19.50	.69	19.70	.88	20.04	.78	20.12
Average.....	.37	20.46	.94	19.74	.63	19.70	.78	20.04	.70	20.15
Circulating-air chamber:										
Average.....	.41	20.45	1.11	20.20	.41	20.44	.85	20.04	.73	20.10

<sup>1</sup> Analyses made at end of longest periods with closed doors.

Before 1940 a material was sought with which to surface the walls and ceiling of the experimental chambers in order to retard the escape of carbon dioxide. Several commercial firms were questioned as to the permeability of various surfacing materials to carbon dioxide. Because no pertinent information was obtained, a method was devised and a series of tests was made to determine the rate of penetration of carbon dioxide through about 20 different surfacing materials or combinations. All determinations were made at laboratory temperatures and an arbitrarily chosen and maintained 20-percent carbon dioxide gradient.

Remarkably wide differences were found between some common surfacing materials in the resistance they offered to the passage of carbon dioxide. These differences were expressed as logarithms of the reciprocals of the relative rates of diffusion of carbon dioxide through the material, in a manner similar to that used for expressing hydrogen-ion concentration. The three most effective materials tested were a paint prepared specially for these tests by a Pasadena firm, white shellac, and a white bathroom enamel. All of these were more than 200,000 times as resistant to the passage of carbon dioxide as plain moist three-ply board. Four paints tested showed an effectiveness between 10,000 and 100,000 times that of moist three-ply board. Among the tests of these was a surface consisting of two coats of a hand-prepared paint composed of white lead, linseed oil, and turpentine. This paint was finally chosen for surfacing the experimental storage chambers because of its relatively low cost and high effectiveness.

During 1940 the carbon dioxide content of the ventilated chamber was less than 0.1 percent by all analyses, but in the circulating-air

one it built up to nearly 1.5 percent during any week in which the door remained closed. In one case when the doors were closed for 16 days the carbon dioxide reached 2.86 percent. However, it is probable that the average carbon dioxide concentration for the season did not exceed 1 percent in the circulating-air chamber.

## INTERNAL CASES OF LEMONS

From June 28 to August 25, 1938, numerous samples were taken for analysis of the internal gases of lemons in the storage chambers. With a few exceptions these lemons were from Corona, but they differed in stage of maturity, time of picking, and condition of storage.

The differences in carbon dioxide and oxygen content of the samples were interesting, though possibly of little significance in connection with the storage problem. Examples of the sort of differences encountered are shown in table 4, which gives the results of one series of analyses of the internal gases of lemons that had been picked from the same orchard block at Corona April 16 and stored April 19 for approximately 11 weeks. As dark-green lemons were very scarce in the grove, it was with some difficulty that three boxes one-third full were obtained from the same block.

TABLE 4.—Internal gases of lemons of various maturities stored about 11 weeks under different conditions, 1938

Storage position	Period with closed door	Carbon dioxide content just before opening door	Date of test	Maturity of fruit when stored	Gas content of fruit		
					Gas extracted in 5 minutes	Carbon dioxide	Oxygen
	Days	Percent			Milliliters	Percent	Percent
Commercial room.....	0	0.1	July 6.	Tree-ripe.....	52 52	3.53	18.80
				Silver.....	70 83	2.23	19.10
				Light-green.....	37 65	4.39	17.26
				Dark-green.....	30 30	4.69	16.80
				Average.....	49 43	3.74	18.14
Circulating-air chamber.....	7	.66	July 8.	Tree-ripe.....	69 15	3.02	18.47
				Silver.....	81 49	1.78	20.16
				Light-green.....	53 43	3.61	17.30
				Dark-green.....	48 45	3.88	17.32
				Average.....	63 36	3.07	18.31
Still-air chamber.....	7	.54	July 7.	Tree-ripe.....	72 90	4.28	17.83
				Silver.....	82 40	2.59	18.88
				Light-green.....	54 25	5.85	14.15
				Dark-green.....	51 65	5.80	15.24
				Average.....	65 15	4.60	16.54

Each sample of lemons used for gas extraction weighed approximately 650 gm. The number of fruits per sample was usually seven. The extraction time for each sample was 5 minutes, with the aspirator bottle lowered to a shelf that allowed an initial negative pressure of 70 cm. of mercury.

The greatest average volume of gas extracted in 5 minutes was from lemons in the still-air chamber and the least from those in commercial storage (table 4). This is probably due to the fact that the shrinkage of fruit was greatest in commercial and least in the still-air chamber. With respect to stage of maturity, the volume yields of gas from the samples was in the following decreasing order: Silver, tree-ripe, light-green, and dark-green lemons. This order may be due to a decreasing

compactness of tissue with advancing maturity until the silver or perhaps the tree-ripe stage is reached. The tree-ripe lemons had a more rapid rate of shrinkage, which may have changed the order; also, they may show more compactness than the silver lemons on account of their generally smaller size and slower growth rate.

The volume yield of internal gas seems to be definitely correlated with its carbon dioxide and oxygen percentages. High oxygen and low carbon dioxide are associated with a large volume of extractable gas and low oxygen and high carbon dioxide with a small one; so the samples from the four stages of maturity may be listed in the same descending order for oxygen as they were for gas yields and in ascending order for carbon dioxide.

### ALTERNARIA DECAY

The inspections for alternaria decay were in the main external. To have had sufficient fruit for representative samples for cutting at each inspection would have required an impracticable quantity. However, particularly during 1938, extra fruit was reserved for cutting. Whenever the first alternaria decay was detected externally in an experimental lot, 40 to 60 fruits of that lot were cut in an attempt to determine the amount of hidden alternaria decay. As such inspection seldom disclosed additional decay in more than 1 percent of the lemons, it finally became the practice to regard as the date of decay break the one when 2 percent of an experimental lot had alternaria decay visible; thus, decay break means that alternaria decay may be present in 3 percent. Before the time of decay break sometimes 1 to 2 percent of the fruit showed decay due to blue and green molds or other organisms, but *Alternaria* must have attacked at least 2 percent of the fruit before the decay-break point was regarded as having been reached. The term "alternaria decay, or rot," in this bulletin is based not upon critical mycological determinations of *Alternaria citri* Ell. and Pierce, but upon careful inspections for those black decays of lemons in storage commonly grouped as alternaria rot. As so used it holds its practical interest for managers and foremen of lemon packing houses.

The data showing the characteristic response of lemons to alternaria decay in storage were plotted with the emphasis on the percentage of fruit remaining sound after each inspection rather than on the amount of decay itself. This method produces a graph that may be called the complement of one directly showing decay. The difference between 100 and the percentage of fruit sound represents the percentage of decay.

The comparative effects on storage life, of storage position, stage of maturity, time of picking within the season, and year are given in table 5 for the period when the still-air chamber was in use and are shown graphically in figures 1 and 2. The data at hand permit little to be said about either the year or the locality in which the fruit was grown.

The still-air chamber in general made a poorer showing than circulating-air and commercial storages, and commercial storage gave a considerably better performance regarding decay and length of storage than did the circulating-air chamber. The shrinkage in weight, however, was less in the circulating-air chamber than in commercial storage (table 1). The resulting greater firmness of the fruit in the former position caused it to appear superior to that in commercial storage, but this apparent advantage was lost soon after the samples were brought into the laboratory.

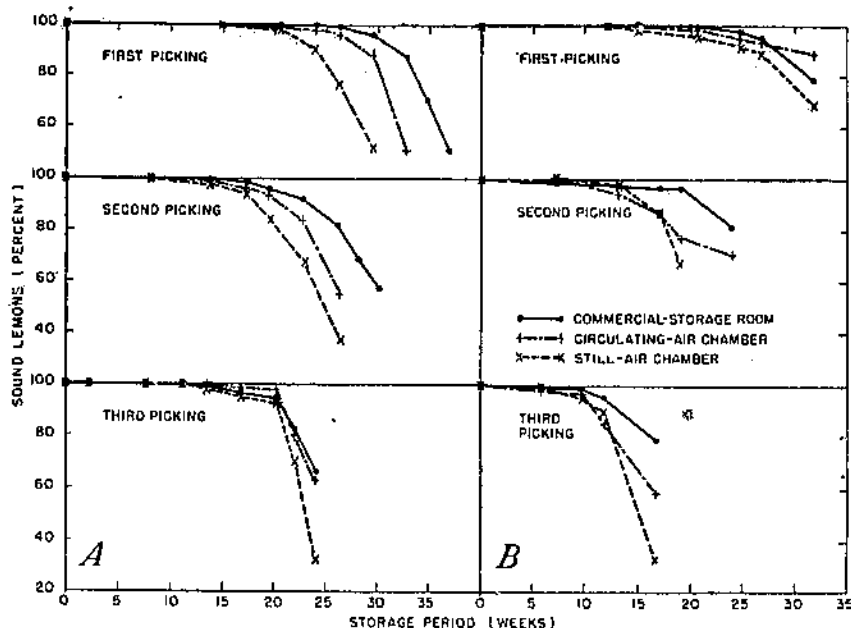


FIGURE 1.—Silver lemons that remained sound after different periods of storage under different conditions, Corona, block 23. *A*, 1938: First picking, February 28; second, April 13; third, May 29. *B*, 1939: First picking, February 14; second, April 7; third, May 13.

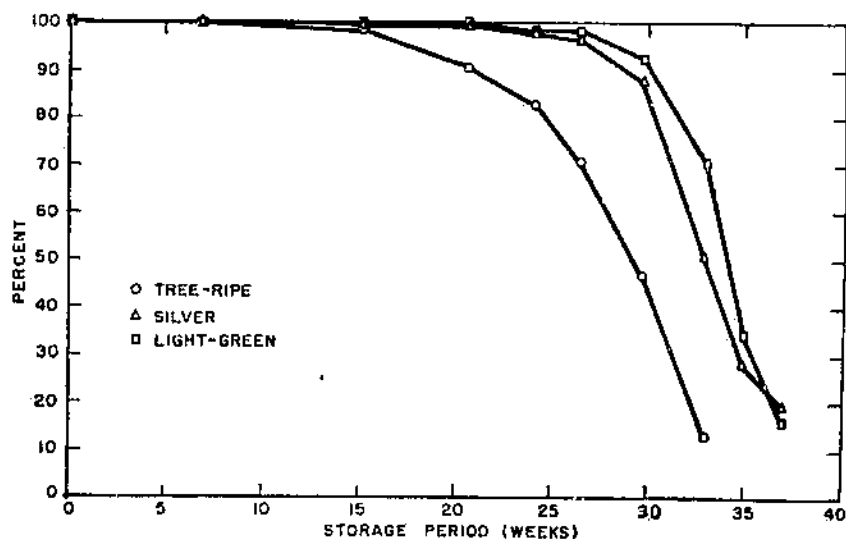


FIGURE 2.—Lemons of different maturities that remained sound after different periods in the circulating-air chamber, Corona, 1938; picked February 28 and stored March 2.

In 1940 the still-air chamber was abandoned in favor of a ventilated one (p. 7), but the circulating-air chamber without ventilation was retained. The results in general corroborated the findings of the two previous seasons. However, the circulating-air chamber proved less favorable than in previous seasons, probably because at the beginning

TABLE 5.—Storage periods of lemons of different stages of maturity, picked at different times and stored under different conditions

Origin of fruit and date stored	Condition of fruit at end of storage period	Storage period of fruit of specified stage of maturity in indicated position											
		Dark-green			Light-green			Silver			Tree-ripe		
		Com- mercial room	Circulat- ing-air chamber	Still- air chamber	Com- mercial room	Circulat- ing-air chamber	Still- air chamber	Com- mercial room	Circulat- ing-air chamber	Still- air chamber	Com- mercial room	Circulat- ing-air chamber	Still- air chamber
<i>1938</i>		<i>Weeks</i>	<i>Weeks</i>	<i>Weeks</i>	<i>Weeks</i>	<i>Weeks</i>	<i>Weeks</i>	<i>Weeks</i>	<i>Weeks</i>	<i>Weeks</i>	<i>Weeks</i>	<i>Weeks</i>	<i>Weeks</i>
Corona, block 23:	No decay				20.5	20.5	14	23.5	20.5	14	14	13.5	12
March 2	Decay break				27.5	27	22	28.5	25	21	21	16	14.5
April 16	No decay				15	9	8	15	9	10	9	8	7
	Decay break				25	16.5	12	19	18	17	16	14	11
May 31	No decay				11	12	15	11	14.5	8	4	4	4
	Decay break				10.5	18.5	18.5	14.5	17.5	14.5	12	11.5	4.5
Piru:	No decay		19	14	24	19	15	12	12	11			
March 10	Decay break		25.5	22	27.5	24	18	21	18	14			
Glendora:	No decay	20	22	15	22	14	6	12	12	11			
March 3	Decay break	27	28	22	28	24.5	15	21	15	13.5			
April 6	No decay				12	16	17	10	10	9	9	9	9
	Decay break				19	20.5	20.5	15.5	16	15	12.5	10.5	10
San Juan Capistrano:	No decay	12	12	12	13	12	12	12	12	12			
March 4	Decay break	23.5	24.5	19	23.5	24	20	24.5	20	17			
<i>1939</i>													
Corona, block 23:	No decay				25	21.5	15	22	16	12	4	9	4
February 16	Decay break				34	29	22	25.5	23	16.5	12	12	6.5
April 10	No decay							5	7	7	6	2	1
	Decay break							17	10.5	13	10	8.5	2
May 17	No decay				11	7	6.5	4	2	4	1	5	1.5
	Decay break				15	11.5	10	11	8	8	5	4	0
Corona, block 11:	No decay							20	20	9	11	10	9
March 9	Decay break							23	25	17	13	14.5	15
April 25	No decay							7	5	6	5	1	2.5
	Decay break							13	8.5	2	9	2.5	8
Corona, block 35:	No decay							6	6	5	1	2	.5
April 4	Decay break							11	10	11	9	8	1
May 17	No decay							2	2	3	1	1	1
	Decay break							6	6	8	4	2.5	2.5

of the season the storage chambers had received two coats of a paint specially selected for its imperviousness to carbon dioxide. Thus, the circulating-air chamber was much more nearly gastight, as shown by the higher build-up of carbon dioxide during the periods between necessary entrances into it. The fruit in the ventilated chamber had a longer storage life and was superior in every way except for more loss in weight to that in the circulating-air chamber. The results from the ventilated chamber were almost identical with those from commercial storage.

### PROGRESSIVE CHANGES IN LEMONS DURING STORAGE SIGNIFICANCE OF DECAY BREAK

The decay records for the 4 years (1938 to 1941) of lemon-storage work show remarkable uniformity, even though the fruit used represented different localities, dates of picking, and stages of maturity and received different storage treatments. The most important difference between the lots was the length of time in storage before the development of serious *Alternaria* decay, or decay break (p. 10). The length of time that lemons could be held in storage before decay break varied greatly with the stage of maturity, time of picking, and condition of storage, but when decay break occurred the rate of subsequent decay soon became rapid and then was practically uniform for all lemons regardless of their original storage qualities. The decay break is a stage of considerable interest, because apparently at this stage, or near it, lemons change from a condition of almost total immunity to *Alternaria* to one of extreme susceptibility.

### INFLUENCE OF VARIOUS FACTORS ON POSSIBLE STORAGE PERIOD

It is well known that the stage of maturity, or color class, at the time of picking has a great influence upon the possible length of time that lemons may be held in storage. Nevertheless, the numerous quantitative data concerning this relation accumulated during the course of these studies seem of sufficient interest to be reported briefly (table 5 and fig. 2).

In general, the order of increasing keeping qualities of the four color classes is tree-ripe, silver, light-green, and dark-green. Sometimes, however, the orders of adjacent classes picked near the same date are reversed as to keeping quality. The writer has not seen the order of tree-ripe and silver lemons reversed but at times has found them behaving very similarly. Some packing houses separate silver lemons into two grades, the poorer of which is then handled much as tree-ripe ones. The classification of lemons as to maturity on the basis of color, as commonly employed, is fairly accurate for fruit picked near the same date, but it does not always afford a means of obtaining fruit of the same maturity when the harvesting is done at widely different dates. That is, silver lemons picked in February are not necessarily comparable with those picked in May, but the relation between the maturity of silver lemons and that of dark-green ones in February is relatively the same as that found between those of similar color classes picked in May.

Lemons with the best storage qualities are harvested in midwinter. After February the keeping quality noticeably diminishes until late spring and early summer; from this point in the season the keeping quality seems gradually to improve until the midwinter maximum is reached. However, over a considerable part of this period of improving

keeping quality the lemons are usually picked and marketed at once, so that little or no storing is done. The initiation of the change for better quality in midsummer seems to be due to the gradual coming into the pickings of lemons developed from bloom of the late summer or autumn of the previous year.

The time of picking has a relatively great influence on keeping quality (table 5). For example, in 1939 light-green lemons from Corona, block 23, picked February 14 were held 1 week on the racking-house floor and afterward 24 weeks in commercial storage without any visible alternaria decay and 33 weeks to their decay break. Light-green lemons picked May 13 from the same block and similarly stored were held only 11 weeks without visible alternaria decay and 15 weeks to their decay break. Thus, the light-green lemons of the lot picked 13 weeks earlier did not reach their decay break until 6 weeks after the later lot had reached it. This is not an extreme case, for it is a common experience for lemons of different maturity classes picked in January and February to outlast in storage those of corresponding color classes picked from then into May. It is for this reason that lemons picked later often are removed from storage for sale while those of the same maturity picked earlier are held. It may be concluded that lemons do not store nearly so well on the tree as in modernly equipped lemon-storage rooms. However, there are many factors involved in the differences noted, one of which is the period of growth. The lemons picked later generally represent fruit that had not reached commercial size when the earlier pickings were made; hence, they were probably set at later dates. If all the winter crop of lemons were of proper commercial size and storage facilities were available, there would be no doubt as to the desirability of picking the entire crop as early as possible and placing it in storage.

TABLE 6.—Average length of storage period for each general picking of lemons, 1938-39

Picking	1938		1939	
	Date stored	Storage period	Date stored	Storage period
First.....	March 2.....	Weeks 22.8	February 22.....	Weeks 23.4
Second.....	April 19.....	10.5	April 10.....	9.6
Third.....	May 31.....	14.5	May 17.....	8.6
Average.....		17.0		13.9

In view of the fact that the various qualities of citrus fruit are assumed to vary greatly with the season (year), the average length of the storage periods of lemons until the decay break was calculated for all Corona lots held in commercial storage in 1938 and 1939. Three groups of picking dates were selected and called first, second, and third pickings for each year. The date used for each picking was the average of the dates of each group of pickings. The average length of the storage period for each general picking is given in table 6. The three general pickings of 1939 averaged 8, 9, and 14 days, respectively, earlier than the corresponding ones in 1938. This should have given the lemons of 1939 some advantage over those of 1938, but they failed to make as good a showing.

Another example of difference in keeping quality of lemons, probably due to season (year), is the following: Dark-green lemons picked

August 17, 1940, from Corona, block E 13, were held in storage 31 weeks before decay break; but those of the same color class picked August 16, 1941, from the same location in the grove, were held only 11 weeks before decay break.<sup>5</sup>

### RESIDUE-SOLIDS RATIOS

Among the changes taking place in lemons during storage it seemed probable that those in the pectic acids, hemicellulose, and other wall materials would be involved. The writer had made numerous determinations of methoxy and uronic acid groups in such materials as remained in the water-insoluble fraction of grapefruit tissue and had found the available standard quantitative methods very unsatisfactory for following specific changes that might be induced by experimental treatment. With this difficulty in mind, it seemed advisable to avoid the involved and expensive methods mentioned and to adopt frankly some simple one that might integrate a group of complex factors with sufficient accuracy to show the trend of the changes in the wall material in lemons during storage. Fifteen different solvents were tried for the purpose of causing mild to drastic effects upon the solubilities of these substances in lemon tissue. After the general trials, four solvents—water, sulfurous acid, acetic acid, and bromine water—were retained for use in the regular determinations; after a few weeks the acetic acid and the bromine water treatments were discontinued. The result obtained by employing this method was called the residue-solids ratio.

The procedure for determining the residue-solids ratio became standardized as follows: A sample consisted of 12 lemons, totaling about 1,000 gm. The lemons were quartered and ground very fine with the nut-butter attachment of a food chopper. The escaping juice was recovered and carefully stirred back into the ground pulp, and the entire sample was thoroughly mixed. From this freshly mixed sample 25-gm. portions were taken for determining total solids. These portions were covered with alcohol and dried in an oven at 77°C. Other 50-gm. portions were transferred to 1-liter flasks, and 900 ml. of the treating solvent was added. For the larger part of the work, as inferred, there were 2 solvents only—water and 12- to 13-percent sulfurous acid. The samples were stirred during the 24-hour treatment period. At the end of this time the entire contents of each flask were transferred to a 3-liter beaker, the top of each beaker was tightly covered with cheesecloth, and the contents were washed vigorously and continuously with tap water for 10 to 12 minutes. The weight of the fine solid material escaping through the cheesecloth did not exceed 0.01 gm. and was therefore negligible in this work.

Ordinary filtering procedure required many hours, and the material was less thoroughly washed than by the rapid method just described. The washed insoluble fraction, or residue, was transferred to an evaporating dish for drying and weighing. The residue-solids ratio was calculated by dividing the weight of the residue from 50 gm. of fresh tissue by twice the weight of the solids from 25 gm. of fresh tissue. This value, or ratio, was then doubled in order to bring all the values above 0.100, as many of the earlier ratios resulting from treatment with more drastic solvents were less than this value.

The first tests with the residue-solids ratio method were on lemons

<sup>5</sup> A. C. Barnes, of the American Fruit Growers, Inc., confirmed these indications from his own general observations of the relative storage performance of the summer lemons of the two seasons named.

representing different stages of maturity. In figure 3 are presented some of the results obtained for dark-green, light-green, silver, and tree-ripe lemons by treating the ground tissue with the following solvents: Water, 20-percent acetic acid, 15-percent ammonium hydroxide, and 12- to 13-percent sulfurous acid. The greater the amount of insoluble solids, or residue, the greater the size of the ratio. As most of the insoluble solids are cell-wall materials, the values given indicate strongly that the four maturity classes differ considerably in these wall substances.

The differences disclosed by the residue-solids ratio in regard to stage of maturity encouraged the hope that it might also indicate changes during long storage periods. Consequently, tests were started at once on lemons from storage at Corona. All experimental lemons held there had been stored as silver. Table 7 presents the results of the tests with the residue-solids ratio made on this fruit from April 3 to September 25,

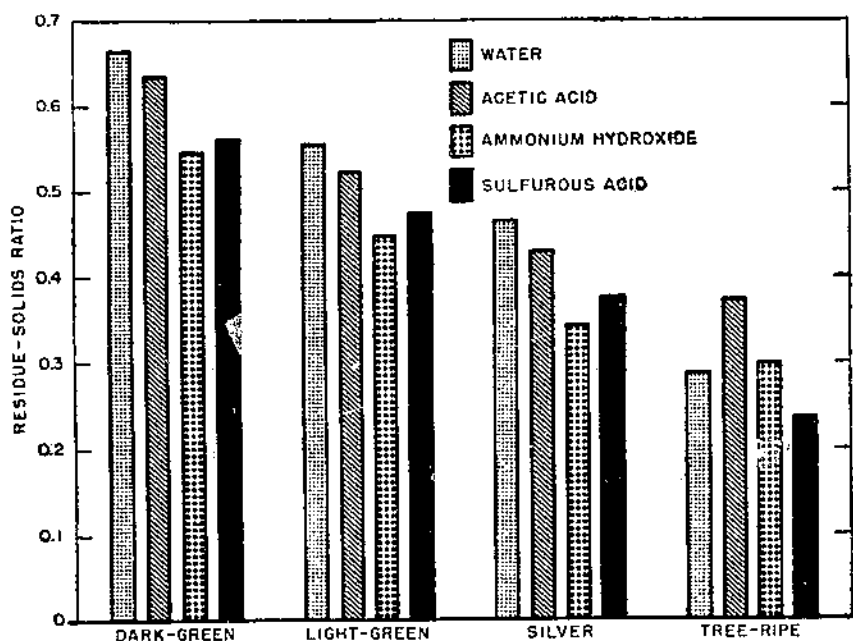


FIGURE 3.—Effects of different solvents on residue-solids ratios in lemons of different stages of maturity.

1940. The results from the three general picking groups and the three storage positions are given separately, but each value in the table represents an equal quantity of fruit from three blocks in the same grove. The results show a rather steady decrease in the ratio to a minimum near the close of the storage period, followed in general by a slight increase.

The fruit in commercial storage and that of the first picking received the most attention in these tests. A comparison of the general results of the three storage positions indicates that the relative humidity, as it affects shrinkage, influences the value of the ratio, probably through the effect of water content on the hydrolysis and synthesis of wall substances. The shrinkage, or drying, toward the end of the storage

TABLE 7.—Changes in the residue-solids ratio in lemons during storage from April 3 to September 25, 1940

Storage position and picking	Solvent <sup>1</sup>	Residue-solids ratio											
		Apr. 3	Apr. 10	May 7	May 15	May 28	June 17	June 27	July 1	July 12	Aug. 3	Aug. 23	Sept. 25
Commercial room:													
First.....	Water.....	0.446		0.440		0.398	0.408	0.346			0.352	0.329	0.365
	Acid.....	.374		.318		.364	.286	.296			.284	.282	.304
Second.....	Water.....	.450		.382		.352	.318		0.208		.328	.321	.335
	Acid.....	.366		.314		.314	.264		.240		.274	.284	.284
Third.....	Water.....			.355	0.359	.330	.328			0.328	.360	.320	.345
	Acid.....			.278	.290	.293	.268			.258	.278	.274	.288
Circulating-air chamber:													
First.....	Water.....		0.460		.445			.442			.342	.324	.321
	Acid.....		.420		.412			.372			.294	.290	.290
Second.....	Water.....								.290		.336	.307	.317
	Acid.....								.236		.280	.261	.276
Third.....	Water.....									.328	.332	.316	.316
	Acid.....									.258	.268	.252	.250
Ventilated chamber:													
First.....	Water.....		.468		.423			.348			.344	.348	.362
	Acid.....		.306		.381			.306			.208	.283	.290
Second.....	Water.....								.374		.312	.351	.351
	Acid.....								.229		.284	.302	.283
Third.....	Water.....									.338	.322	.320	.330
	Acid.....									.274	.272	.266	.271

<sup>1</sup> Acid was 12- to 13-percent sulfurous.

period might account for the rise in value of the ratio through resynthesis. Fruit in commercial storage showed the most shrinkage and that in the circulating-air chamber the least. The increase in the residue-solids ratio near the close of the observation period was also least in the circulating-air chamber, and none is shown for the fruit of the first picking.

The maximum percentages of change in the residue-solids ratios during the storage periods are shown in table 8. In the lemons in commercial storage the average rate of increase of the ratio per week, after it had reached its average minimum, was 1.15 percent as compared with the average decrease of 1.64 percent per week before the minimum was reached. The minimum ratios in the lemons in commercial storage show a fair correlation with the decay break, but the evidence does not seem to justify the assumption that it is significant. In general, however, the method has indicated that some very striking changes take place in lemons in storage and upon the tree as they develop from commercial-size, dark-green to tree-ripe maturity.

TABLE 8.—Maximum decreases of the residue-solids ratios in lemons in storage

Storage position and picking	Solvent <sup>1</sup>	Decrease of ratio	Storage period	Average decrease per week
		Percent	Weeks	Percent
Commercial room:				
First.....	Water.....	26.2	20	1.3
	Acid.....	24.6	20	1.2
Second.....	Water.....	33.8	13	2.6
	Acid.....	34.4	13	2.6
Third.....	Water.....	15.7	13	1.2
	Acid.....	7.2	7.5	.96
Average.....		23.7	14.4	1.6
Ventilated chamber:				
First.....	Water.....	26.5	16	1.7
	Acid.....	24.7	16	1.5
Circulating-air chamber:				
First.....	Water.....	30.2	24	1.3
	Acid.....	31.0	19	1.6

<sup>1</sup> Acid was 12- to 13-percent sulfurous.

The method might be improved by the choice of more suitable solvents and better procedures for applying them. The sampling especially could be improved. In the present study the entire lemon, including rinds and seeds, was taken as a sample. The seeds alone must have introduced a considerable variable as well as a dilution of the main critical changes in which there is most interest. The method used in relation to susceptibility to *Alternaria*, for example, probably should deal only with the central core of tissue, which is often the first to be invaded by the fungus.

### BUTTON CONDITION

#### TALLYING OF BUTTON CONDITION

Those who work with citrus fruits, especially lemons, usually observe the condition of the buttons as to whether, for example, they are black, brown and shriveled, or green and plump; they then employ the results of these observations in a general way as an aid in judging the quality of the fruit. Fawcett (4, p. 590), in writing of storage decay in lemons, made the following statement:

The separation of beginning stages of alternaria rot is especially difficult. It is being done, however, in a rough way in some cases by such indefinite signs as "high color," "black button," "button off," "black at scar," and "soft fruit," but some more definite, satisfactory method still remains to be evolved. The presence of large percentages of black buttons is an indication of potential decay, especially alternaria rot, . .

Early in the lemon-storage studies in 1938 the writer made some statistical examinations of button conditions. For example, on June 1 and 2 button inspections were made on half of the contents of each of 36 boxes of lemons, grown in such separated localities as Corona, Glendora, San Juan Capistrano, and Piru. The pickings were made February 24 to 28. At the time of storage the fruit had been classified as follows: 3 boxes of tree-ripe, 12 of silver, 12 of light-green, and 9 of dark-green. The period in storage had been about 13 weeks. Four categories were chosen in which to tally the buttons: (1) Green (dark-green and tight, light-green), (2) dark, (3) moldy, and (4) off. The moldy buttons usually belong also to the dark class. The results of the inspection of half boxes showed the following percentages of buttons that were green: For tree-ripe lemons, 35; silver, 56; light-green, 72; and dark-green, 87.

After the button inspections in 1938 no tallies were made for 2 years, largely because the figures, though interesting, did not seem to lead anywhere. However, in July, 1940 some observations made it seem worth while to follow statistically the change in button condition from week to week. All the experimental lemons on hand at the time were silver, but after July small lots of those in other stages of maturity were obtained from time to time for observation of buttons. Subsequently, more than 60 half boxes of silver lemons were inspected for button condition at intervals of 2 to 4 weeks. After 13 weeks of storage at Corona silver lemons showed an average of 50 to 55 percent of the buttons remaining green. This percentage is very close to the average for the 12 half boxes of silver lemons inspected in 1938.

#### CLASSIFICATION OF BUTTONS

Before beginning this phase of the study the system of classification of button condition had to be somewhat altered, so that it could be used with rapidity, but with sufficient accuracy for the observer to approximate closely previous inspection figures for a given lot on

immediate reinspection. The main sources of error lay in the borderline cases.

The five categories of buttons adopted are described as follows:

*Full-green.*—Dark-green, fresh-looking buttons, green to the very margin and with the marginal lobes tightly appressed; also light-green, fresh-looking, rather uniformly colored ones with appressed margins.

*Intergreen.*—Two general types of buttons are included here. One is dark-green, often unusually thick or plump but with margins dry, brown, and dead. Fruit having this type of button is common in late spring and throughout the summer, with maturity classification of light- or dark-green, especially the latter. In some lots direct from the grove as high as 50 percent of the buttons are of this type. These buttons are placed somewhat doubtfully in the intergreen class because they seem to be associated with fruit poorer in keeping quality than is normal for its maturity classification. The other type of intergreen button is very light green to light brownish yellow, beginning to dry, and with margins only slightly appressed.

*Interblack.*—In this class are included buttons that are still rather turgid; they may have considerable clear yellow but show one or more black patches. Their margins are seldom appressed.

*Full-black.*—The buttons are black throughout, mostly dry, with margins turned back from the fruit surface. They are often moldy.

*Off.*—When buttons fall from green fruit during washing and other handling operations preceding storage, the scars usually callus and the lemons seem to keep as well as those with buttons intact. Such lots may start their storage with, for example, 3 percent of the buttons off, and 15 to 20 weeks later the tally may still show the same 3 percent off; but the dropping of many buttons after the lemons are stored indicates an unfavorable condition. Tree-ripe lemons are especially prone to drop buttons in storage.

#### RELATION OF BUTTON CONDITION TO ALTERNARIA DECAY

The classification of lemon buttons as described was employed in the inspection of more than 90 lots of fruit, with an average of 7 inspections per lot at intervals of 2 to 4 weeks. Some of the typical results of these inspections are discussed in this section.

The data on the button conditions of three typical lots of lemons at different inspections are given in table 9. The cumulative alternaria decay at each inspection date is also given. There were about 1 percent of the lemons with buttons off in each of the three lots during the entire storage period. The percentage of buttons in each class changed with each inspection. The full-green buttons decreased from the beginning of storage, at first slowly and then faster to a relatively rapid rate. After decay had appeared in 5 to 15 percent of the fruit, the rate of the full-green-plus-intergreen decrease usually became slower again. The change in the full-green class proved to be the most uniform. The full-green buttons changed to intergreen, the intergreen to interblack, the interblack to full-black; the full-black button class then lost to alternaria decay. This change of buttons from class to class was not uniform and resulted in considerable fluctuation, especially in the intergreen and interblack classes. However, the full-black buttons increased steadily to a point when the rate of decay became more rapid than the transformation of buttons from the other classes to full-black. As to the statement just made that the full-black class lost to alternaria decay there seems to be no relation between button condition and decays caused by blue and green molds; but the writer has not seen what appeared to be alternaria decay in any lemon that did not show a full-black button.<sup>6</sup>

<sup>6</sup> Dr. H. S. Fawcett, however, brought to the writer's attention the fact that rarely *Alternaria* may invade lemons showing green buttons but the point of entry of the fungus is then elsewhere than at the button site and apparently the invasions are associated with special types of injury.

TABLE 9.—Results of button inspections of 3 lots of lemons picked March 5 and stored March 6 in commercial storage, Corona, 1941

Maturity when stored and date of inspection	Buttons in indicated class					Fruits decayed (cumulative)
	Full- green	Inter- green	Full- green plus intergreen	Inter- black	Full- black	
<b>Tree-ripe:</b>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>
March 12.....	56	31	96	3	0	0
March 18.....	52	30	91	7	1	1
April 9.....	49	32	81	7	10	2
May 6.....	23	30	53	14	28	5
June 9.....	0	11	11	23	56	9
July 8.....	0	3	3	2	62	30
<b>Silver:</b>						
March 12.....	81	19	100	0	0	0
March 18.....	76	25	100	0	0	0
April 9.....	76	25	100	0	0	0
May 6.....	57	35	92	5	2	1
June 9.....	29	29	58	6	33	2
July 8.....	8	15	23	10	64	4
August 4.....	1	10	11	6	74	8
September 2.....	1	7	8	2	69	22
<b>Light-green:</b>						
March 12.....	84	16	100	0	0	0
March 18.....	84	15	99	1	0	0
April 9.....	70	20	99	0	1	0
May 6.....	74	23	97	1	0	1
June 9.....	68	21	89	6	4	1
July 8.....	47	27	74	4	20	1
August 4.....	20	32	52	11	34	2
September 2.....	15	26	41	2	51	5

It would seem that the darkening of lemon buttons is mainly due to the development of *alternaria* decay within them and that the button is extensively destroyed before conditions within the lemon itself have become favorable for invasion by the causal fungus. This is in accord with Bartholomew's conclusions (1). He concluded also that the buttons are infected at an early stage of development on the tree and that the attack within the fruit is made from the infected button only after certain changes have taken place in the constitution of the lemon. In this connection it has been observed that in many lots of lemons the buttons of 1 or 2 percent remain green throughout storage; this percentage of fruit does not decay but gradually shrivels to dryness, and the buttons dry green. A possible reason for this apparent immunity may be that such buttons escaped the usual *Alternaria* infection in the grove, and hence the fruit escaped *alternaria* decay in storage.

The progress of the changes in the appearance of the buttons is very similar to that of *alternaria* decay in the fruit. The delay in the beginning of the change from green to black correlates closely with the maturity of the lemons when stored; the more advanced the maturity the shorter the delay. The rate of change after initiation is greatest in lemons most advanced in maturity. The fact that these observable changes in the buttons precede *alternaria* decay in a given lot of fruit, often by many weeks, should make them a valuable potential index of the safe storage period.

Plotting the data on change in the condition of the buttons is usually simplified by adding the percentages in the full-green and intergreen classes and calling the sum green. The same grouping may be made of buttons in the interblack and full-black classes, and the sum may be referred to as black. These classes can be so grouped and still give approximately accurate values, especially when for each inspection the percentage value in the individual classes (e.g., full-green and inter-

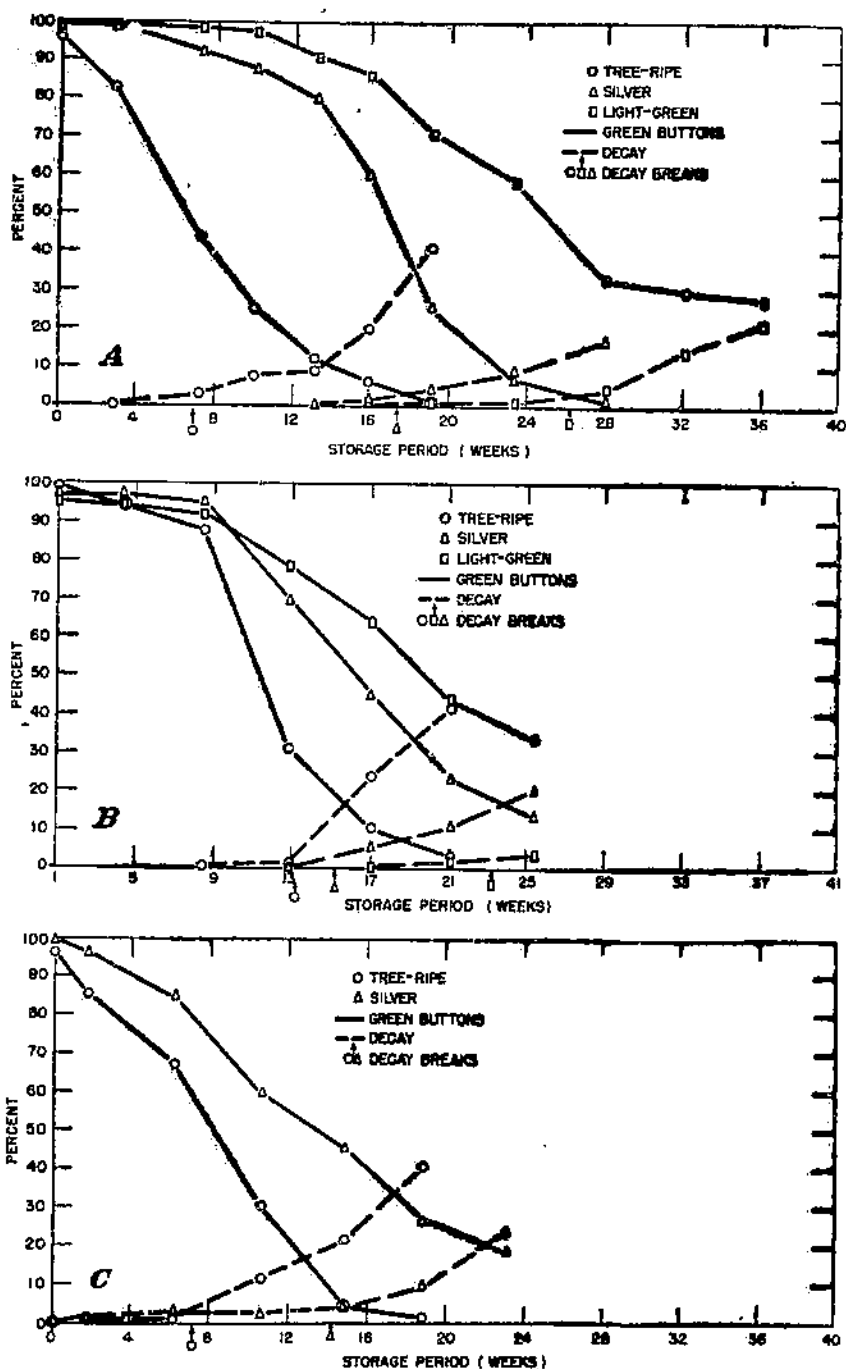


FIGURE 4.—Changes in buttons in relation to decay of lemons of different maturities and after different periods of storage. A, Corona, block W 34, 1940; fruit picked November 25, stored November 28. B, Corona, block 11, 1941; fruit picked March 7, stored March 10. C, Corona, block E 25, 1941; fruit picked March 20, stored March 27.

green) is written beside the graph. If the numbers 54-34 were placed at a point on a graph marked "88 percent green buttons," it would mean that 54 percent of the buttons were full-green and 34 percent intergreen. Figure 4 represents the general features of such graphs without the details that often are placed on working graphs of larger scale.

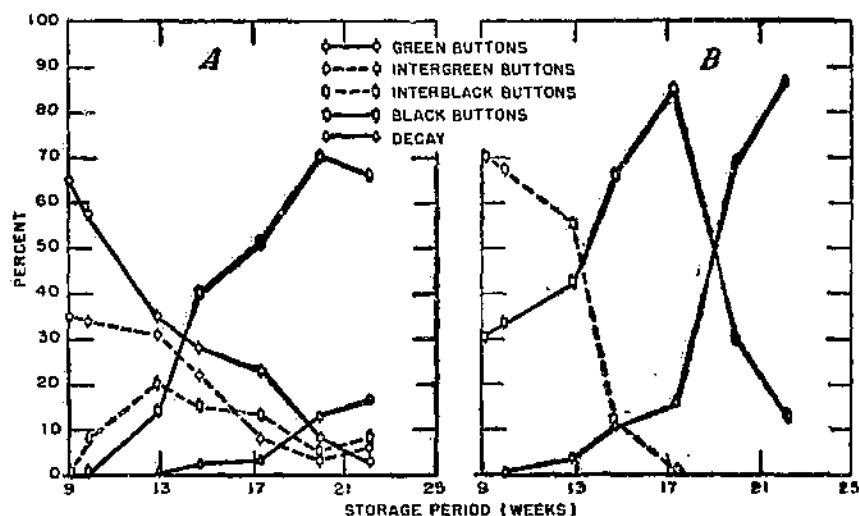


FIGURE 5.—Relation of percentages of buttons in different classes and the decay developing in two lots of commercial lemons picked at Corona May 7, 1940, and selected on July 9 from a packing conveyor after 9 weeks in storage. *A*, Lot with all buttons full-green or intergreen. *B*, Lot with all buttons full-black or interblack.

Figure 5 shows the results of inspecting a single commercial lot of silver lemons picked May 7, 1940, and stored May 8. On July 9 when they were being packed for eastern shipment the writer selected from the packing conveyor one box each of fruit with green and black buttons. The two boxes were carefully inspected with respect to button classification and returned to the commercial storage room for subsequent observations; inspections were continued at intervals for 13 weeks. The lemons selected for green buttons (fig. 5, *A*) did not reach the decay break until about 8 weeks after being put aside, but those with black buttons (fig. 5, *B*) reached the decay break in less than 4 weeks. Thus it appears that after several weeks of storage it would be possible to sort lemons of one maturity classification into fruit that should be shipped at once and that might be safely held for a longer period. However, only an unusual market demand would justify such a sorting.

A good example of the relation of the time of picking to change in button color and decay is shown in some records of three pickings of silver lemons from Corona, block W 34, 1940. The first picking was made February 16, stored February 20; the second, April 1, stored April 5; and the third, May 10, stored May 14. The storage was in the commercial room. The first complete button inspection of these lemons was made after they had been stored 21, 15, and 10 weeks, respectively, and subsequent inspections at intervals of about 3 weeks. At the first button inspection the percentages of buttons remaining green in the first, second, and third pickings were 53, 51, and 74, respectively; but 12 weeks later the corresponding values were 8, 2, and 3 and the percentages of fruit decayed were 15, 23, and 20. The three pickings reached

their respective decay breaks 26, 18, and 15 weeks after picking, when 23, 26, and 38 percent of the buttons were still green.

Figure 6 shows the influence of the storage conditions of the buttons of dark-green lemons picked August 12, 1940, and stored August 15, one lot each in the ventilated chamber, the circulating-air chamber, and the commercial room. The darkening of the buttons was relatively very rapid in the circulating-air chamber between September 9 and November 11. On November 11 lots in the ventilated and the circulating-air chambers were transferred to the commercial room; the rate of button change then became practically the same for all. The rate of decrease in the percentage of buttons that remained green in the circulating-air chamber was relatively more rapid than the progress of decay, as compared with the other two locations. Apparently in the circulating-air chamber with the minimum of ventilation the buttons were affected more severely than the fruit itself, for the decay break was not reached in this fruit until the buttons remaining green had been reduced to about 15 percent. In the other chambers, however, about 40 percent

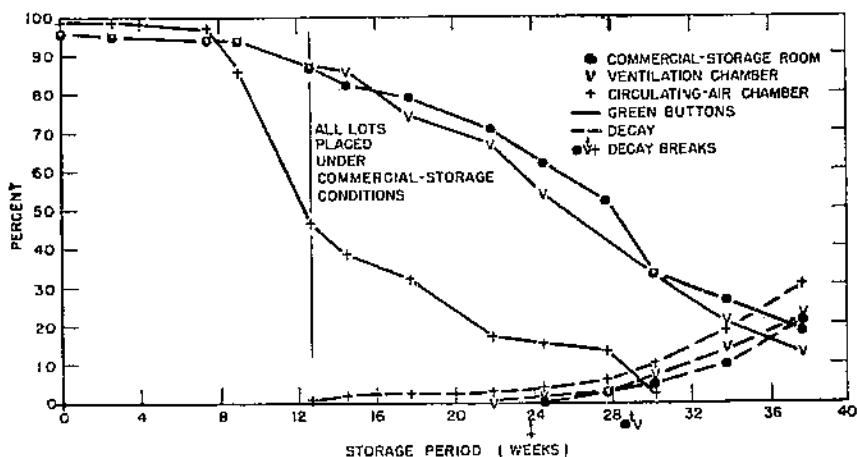


FIGURE 6.—Relation of percentages of buttons remaining green and decay in dark-green lemons picked August 12, 1940, Corona, block E 13, and stored under different conditions from August 15 to November 11 and subsequently under the same conditions.

of buttons were still green at the decay break. It has been observed that the green buttons of lemons commercially treated with nitrogen trichloride gas sometimes are reduced to percentages ranging from 0 to 10 before the decay break is reached.

The practical value of observing changes in the condition of the button must depend upon the constancy of the relation between it and the susceptibility of the lemons to alternaria decay. Experience has already shown that the relation may vary greatly with the storage treatment, but the main problem is to determine how constant it will be in a given commercial lemon storage. Some light will be thrown on this matter by reference to table 10, in which are data for the button condition of 27 lots of lemons held in the commercial storage room at decay break and 4 weeks before. The totals of green buttons at either of these periods varied with the maturity class, date of storage, and other factors. The more mature the fruit at the time of storage the greater was the total percentage of green buttons at the decay break or 4 weeks before. For

the latter period there was an average of 56, 60, 67, and 84 percent of green buttons in dark-green, light-green, silver, and tree-ripe lemons, respectively. One of the best indicators of a probable danger point in the green-button graph for any lot of lemons was the rate of change. Until 4 weeks before decay break the average rate of decrease in green buttons in tree-ripe lemons was 5.60 percent per week (range 3.11-7.72 percent); in silver, 2.45 percent (range 2.01-2.97 percent); and in light-green, 1.95 percent (range 1.52-2.22 percent). There were only 2 lots of dark-green fruit, but they gave an average of 1.73 percent decrease in green buttons per week.

TABLE 10.—*Lemon buttons remaining full-green and intergreen at decay break and 4 weeks before, Corona, 1940-41*

Maturity of lemons when stored and date of storage	Period to decay break	4 weeks before decay break			At decay break		
		Full-green	Inter-green	Total	Full-green	Inter-green	Total
<b>Dark-green:</b>	<i>Weeks</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>
August 17.....	29	24	26	50	17	21	38
Do.....	31	26	35	61	15	29	44
Average.....	30	25	31	56	16	25	41
<b>Light-green:</b>							
November 28.....	26	44	19	63	14	20	43
December 10.....	28	38	18	56	18	24	42
January 3.....	27	30	32	62	21	32	53
January 17.....	26	35	34	69	28	20	57
February 5.....	26	45	15	60	14	36	50
March 4.....	25	28	29	57	15	28	43
March 10.....	23	17	37	54	9	30	39
Average.....	26	34	26	60	17	30	47
<b>Silver:</b>							
November 28.....	17.5	48	30	78	17	25	42
December 10.....	19	37	31	68	24	29	53
January 3.....	25	34	19	53	19	20	39
January 17.....	26	27	29	56	21	26	47
February 5.....	24	19	32	51	7	26	33
March 4.....	16.5	44	30	74	18	23	41
March 10.....	15	43	37	80	19	35	54
March 27.....	14	34	29	63	22	25	47
April 18.....	11	52	29	81	45	21	66
Average.....	19	38	30	67	21	26	47
<b>Tree-ripe:</b>							
November 28.....	7.5	67	15	82	25	10	44
December 10.....	6.5	42	41	83	33	27	60
January 3.....	4	55	34	89	45	37	82
January 17.....	6	50	18	68	43	30	73
February 5.....	8	43	44	87	29	19	48
March 4.....	6	53	37	90	36	37	73
March 10.....	13	50	30	80	21	9	30
March 27.....	7	56	23	79	31	27	58
April 18.....	7	71	21	92	30	12	42
Average.....	7	55	29	84	33	25	58

Toward the close of the observations on buttons here reported it was found that, after about three inspections (including the initial one) 4 weeks apart, the subsequent behavior as to change in the buttons and alternaria decay could sometimes be predicted. This was done by plotting the data for the lot of lemons in question and comparing these uncompleted graphs with completed ones obtained from other experimental lots. Silver and tree-ripe fruit were found to be the most predictable. For tree-ripe lemons a second inspection, 3 weeks after they were stored, was sometimes sufficient to determine within a range of 2 weeks the time of decay break. It was only after a storage period of

8 to 10 weeks and after two or three inspections that the subsequent behavior of silver lemons could be predicted, and light-green ones required about 12 weeks. There have been too few observations on button changes in dark-green lemons to permit any statement, but presumably they would behave in much the same manner as the light-green, since they do so in other respects.

The observations on lemon buttons reported here bring up an old subject in a somewhat different manner. The change in condition of buttons during storage was found to be remarkably regular, on the whole, and to parallel, weeks in advance, those internal changes in lemons that make for increased susceptibility to *Alternaria* invasion. The fact that this change in the buttons is steady and that it precedes the actual fungus invasion of the lemons themselves suggests the possibility of anticipating the safe storage period of any lot of lemons, provided their button condition be carefully observed, recorded, and compared with certain standards. Standards suitable for this purpose would have to be developed from tests made under the different current commercial-storage conditions and would presumably take the form of tables or graphs indicating the expected maximum storage period corresponding to different percentages of green buttons and rates of change in them. The required button inspections themselves would be easily practicable were their value in this connection definitely proved.

The possibility of developing a curve of reference which might be useful in predicting the keeping quality of different lots of lemons is

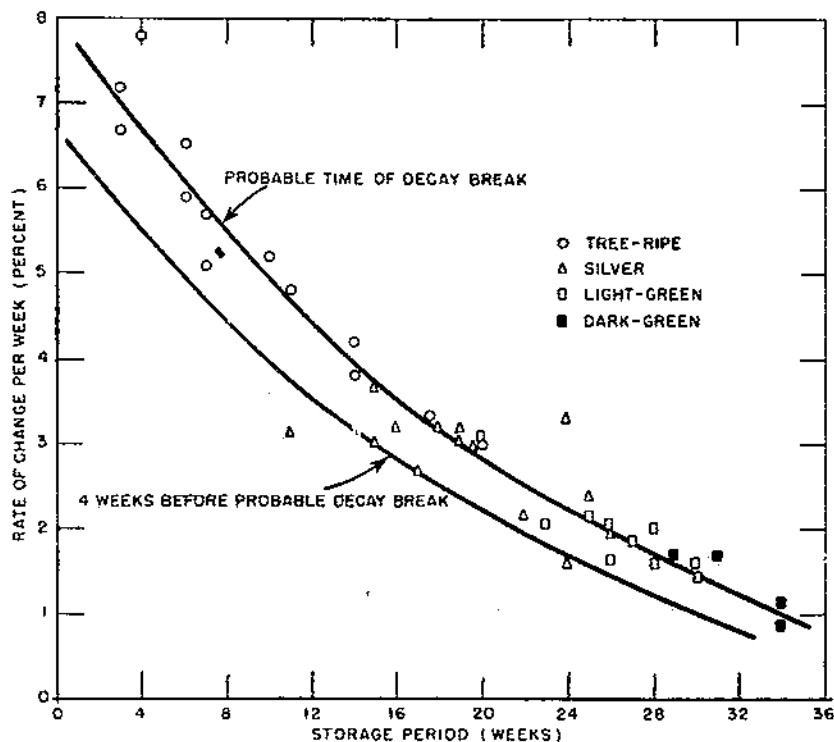


FIGURE 7.—Relation of rate of change of button color from green to black to length of storage period before decay break. (Data from 42 lots of lemons in storage at Corona, 1940-42.)

illustrated in figure 7. In it are plotted the observed lengths of time different lots of lemons were in storage before reaching their decay break. The points in the figure are plotted from the calculated rate of change of button color and the time of decay break of 42 separate lots of lemons; the record of 27<sup>1</sup> of these lots are given in table 10. The curve representing probable time of decay break was constructed with reference to the previously plotted points. The curve labeled 4 weeks before decay break was simply drawn through points at distances from the other curve equivalent to 4 weeks according to the abscissal scale.

The manner in which one might employ such a curve of reference in predicting the probable keeping quality of a lot of lemons just stored would be somewhat as follows: Assume the lot to be silver lemons. The button condition is recorded at the time of storage. The second inspection and retallying of button colors are made in 3 to 4 weeks. A third inspection is made after another equal period of time. The calculated weekly rate of change in buttons from green to black during the period between the second and third inspection may, after reference to the curve, indicate the probable keeping quality. Very weak silver lemons may give some indications at the second inspection; on the other hand, with very strong silver lemons there may be little or no indication of probable decay break before a fourth inspection period. Unfortunately the significance of any weekly rate of change in button color depends upon a number of already recognized factors (p. 22), so that the position and perhaps shape of such a curve of reference as proposed would undoubtedly have to be determined for the particular conditions maintained in individual lemon-storage houses.

### SPECIAL RESPIRATION TESTS

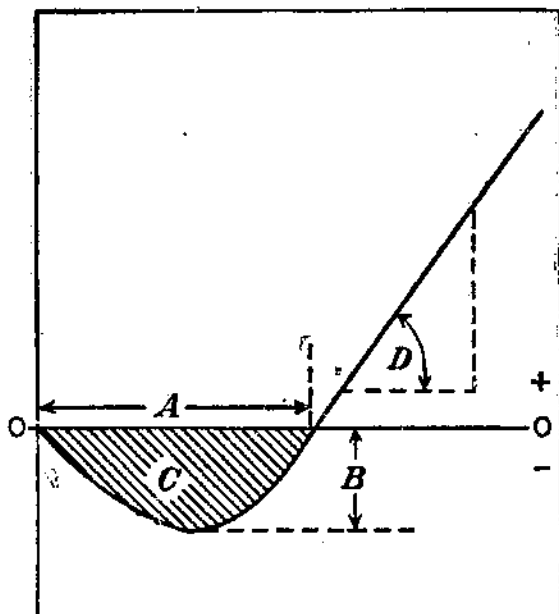
#### CRITICAL RESPIRATION CHARACTERISTICS AND THEIR INTERPRETATION

The special respiration test for citrus fruits described by Harvey and Rygg (5), with further data by Rygg and Harvey (8), was employed from time to time throughout these studies on lemon storage. Formerly the method had been applied to grapefruit, oranges, and lemons, but almost entirely to fruit either direct from the field or stored relatively short periods. From such tests there developed a general interpretation of the resulting respiration graphs based upon four selected critical characteristics (fig. 8). This interpretation regarding the condition of the fruit was as follows: The longer the period of negative pressure (*A*), the greater the maximum negative pressure (*B*), the larger the area (*C*), and the less the slope, or angle, (*D*) the better the condition of the fruit; the converse the poorer fruit. The lower the storage temperature the more pronounced these characteristics became.

During the first 8 to 10 weeks of lemon storage in 1938 the results of the special respiration tests on fruit from the three storage conditions showed, with few exceptions, the commercial storage to be the best and the still-air chamber the poorest, according to the general interpretation of the respiration graph just outlined. This is illustrated by a typical analysis presented in table 11. Here the fruit in commercial storage was interpreted as best, because the values of *A*, *B*, and *C* were the largest and that of *D* the smallest of the three lots. The converse of these conditions made the fruit from the still-air chamber the poorest. The differences were not large but were constant through the tests.

<sup>1</sup>The records of the remaining 15 lots were taken after the original study was completed.

FIGURE 8.—Typical special respiration graph showing critical characteristics: *A*, Duration (in hours) of negative pressure; *B*, maximum negative pressure (in centimeters of mercury); *C*, area bounded by zero abscissa and the portion of the graph below it (in square centimeters); *D*, slope, or angle, between the graph which lies above zero abscissa and any convenient abscissa as indicated (measured with a transparent protractor in degrees).



Therefore, in these results, as in those of all previous studies involving this type of respiration, there have been but few exceptions where any grounds were observed for doubting the foregoing interpretation of the critical respiration characteristics.

TABLE 11.—Critical respiration characteristics of lemons stored in 3 positions, June 1938  
[Values taken from respiration graphs; terms explained on p. 26 and in legend for fig. 8]

Storage position	Duration of negative pressure (A)	Maximum negative pressure (B)	Area (C)	Slope (D)
	Hours	Cm. Hg	Sq. cm.	Degrees
Commercial room.....	48.5	3.3	24.8	64.5
Circulating-air chamber.....	40	3.2	22.6	66
Still-air chamber.....	38.5	2.7	16.6	61

#### RELATION OF STORAGE PERIOD AND CRITICAL RESPIRATION CHARACTERISTICS

As the storage period extended into the summer the respiration tests gave more and more exceptions to the expected behavior of lemons from different storage conditions, maturities, pickings, and button colors. These exceptions decidedly cast doubt upon the previous interpretations of the significance of the respiration graphs as applicable to lemons under the conditions developing.

After much study and comparison of many respiration graphs from tests on lemons differing in storage period, maturity, time of picking, button condition, and amount of *Alternaria* infection, it was finally apparent that the response of very old lemons to the conditions imposed by the special respiration tests were opposite that of fresh ones. This change was interpreted to mean that the potential of fresh, and especially of less mature, lemons for anaerobic respiration was relatively weak, but that it increased during the first weeks of storage, even at

the mild temperature of 56° F. Later the potential for anaerobic respiration gradually subsided until, near the decay break, it became less than that of newly stored lemons. When this stage was reached the general interpretation of the respiration graphs had to be completely reversed to read (fig. 8) as follows: The smaller *A*, *B*, and *C* and the larger *D* the better the condition of the fruit; the converse the poorer the condition. It should be added, however, that when this situation had arrived the fruit was of little commercial value, because of its susceptibility to decay. However, the situation is interesting physiologically, and it was useful in making late-storage comparisons of the condition of lemons.

Evidence of this reversal of response of old lemons to anaerobic condition is presented in figure 9. At the time the respiration tests

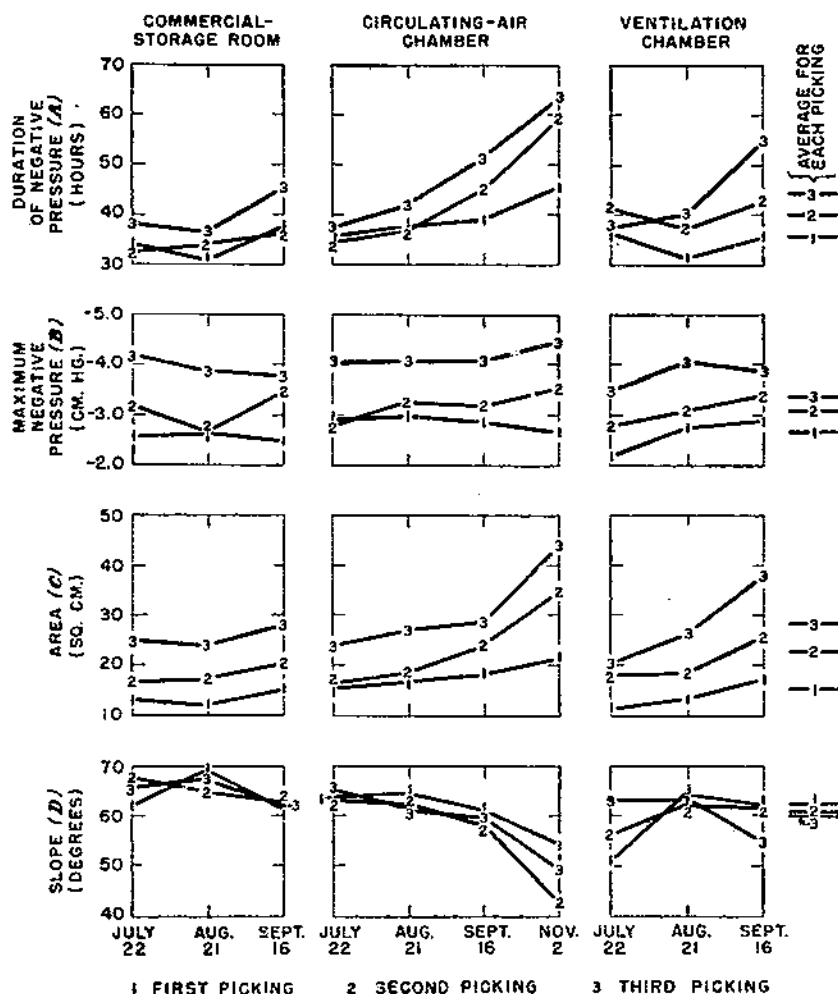


FIGURE 9.—Changes in critical respiration characteristics of lemons after long storage in different positions. (Three pickings from Corona, block W 34, 1940: First, picking February 16, stored February 20; second, April 1, stored April 5; third, May 10, stored May 14.)

were begun with this fruit the three pickings had been in storage approximately 22, 16, and 11 weeks, and they still retained 49, 42, and 68 percent of green buttons, respectively. It was planned to make three separate series of comparative respiration tests on these lots, in order to test for the reversal of anaerobic respirational response as follows: (1) Shortly before the decay break, (2) just afterward, and (3) well beyond it. These were considered critical points for the task in hand; but the fruit lots, representing as they did three storage conditions as well as three pickings, rendered it difficult to anticipate the exact dates on which the test ought to be made. However, the results indicate that the lemons of the first picking from the commercial room and the ventilated chamber were tested at or near the critical points as planned. These lemons were in the best condition, as judged by all standards available. Nearly all fruit of all pickings held in the circulating-air chamber had apparently advanced beyond what was intended as the third test point before the first test was made. A fourth test was made November 2 on the same stock of lemons from the circulating-air chamber, in order to determine how extreme the reversal of behavior might be in old lemons. But by this time only 44, 32, and 17 percent of the first, second, and third pickings, respectively, remained sound.

The data presented in figure 9 indicate that lemons of the third picking were in the poorest condition and those of the first picking in the best, because in most instances the respiration characteristics *A*, *B*, and *C* are the largest for the third and smallest for the first picking. The same interrelation of the three pickings is also indicated by the characteristic *D*, which is smallest for the third picking and largest for the first. Likewise, in comparing the three storage positions it can be seen that the lemons from the commercial room were the best, those from the circulating-air chamber the poorest, and those from the ventilated chamber intermediate but closer to the commercial room.

#### RELATION OF ALTERNARIA DECAY AND CRITICAL RESPIRATION CHARACTERISTICS

The complete reversal of behavior of lemons under anaerobic conditions seemed to take place very near the decay break, although from the evidence at hand the progress toward this condition begins only a few weeks after storage. An example of the evidence will be found in table 12, which shows some changes in value of the critical respiration characteristics of lemons from the beginning of storage. This fruit was picked August 13, 1941, and stored 1 day later in the commercial room. Although it was classed light-green it was considered weak because of the prevalence of endoxerosis, or internal decline. This fact was part of the reason for selecting it for the experiment. However, to avoid as much as possible severe endoxerosis, two experienced graders selected five boxes of lemons from the general lot. Nevertheless, it was found by subsequent cutting of each sample after it was used in the respiration chambers that through the twenty-five 2-gallon respiration chambers of fruit used the percentages of severe endoxerosis ranged from 0 to 2, of medium cases 0 to 6, and of slight or trace 24 to 45.

These inspection records help to account for the rapid changes in the critical characteristics of this fruit in storage (table 12). Normal, winter-picked, light-green and silver lemons showed much slower changes under storage conditions. The data in table 12 indicate that

the lemons had reached their maximum anaerobic respiration capacity within 1 or 2 weeks and a complete reversal (or return to their original fresh capacity) in about 10 weeks. No decay was found until after the October 16 examination. When the inspection was made by cutting after completion of the respiration test beginning December 16, a total of 5.1 percent of the fruit was found affected with *alternaria* rot. By interpolating backward along a working graph plotted from the data in table 12 it was indicated that this sample of lemons probably had reached the decay break November 15 to December 1, with probably 40 to 45 percent of the buttons remaining green at that time.

TABLE 12.—Changes from the beginning of storage in the critical respiration characteristics of lemons at 76° F. stored as light-green fruit, Corona, 1941

[Terms explained on p. 26 and in legend for fig. 8]

Date examined	Approximate storage period	Buttons green <sup>1</sup>	Critical characteristics			
			Duration of negative pressure (A)	Maximum negative pressure (B)	Area (C)	Slope (D)
	Weeks	Percent	Hours	Cm. Hg	Sq. cm.	Degrees
August 16.....	0	97	29	3.7	17.0	72
August 23.....	1	97	21	3.4	11.7	75
September 5.....	3	95	23.5	2.9	11.2	73
September 25.....	6	68	25.5	2.8	12.2	68
October 16.....	9	54	30	3.0	12.0	62
December 16.....	18	36	32	2.9	14.0	58

<sup>1</sup> Green plus intergreen.

The results of all respiration tests also indicate a relation between the button color and the tendency of lemons to alter their response to anaerobic conditions. Table 13 presents the results of four tests of this sort. The lemons of the first three tests recorded in the table were selected for button color from the commercial conveyor as the general lots were being packed for eastern shipment in 1940. On October 8, 1941, a fourth test was made on specially selected lemons which had been in storage 14 weeks and stored as dark-green. When removed to the laboratory for the test the sample showed 34, 24, 35, and 7 percent of the buttons full-green, intergreen, interblack, and full-black, respectively. In this fourth test the lemons showed but slightly the tendency toward reversal of anaerobic response. The lemons were still in excellent condition and a few weeks away from their decay break; but in these and in the other examples of table 13, the reverse formula can mostly be applied; that is to say, lemons with the lighter colored buttons are better in general, as indicated by showing smaller A's, B's, and C's and larger D's.

#### EFFECT OF ALTERNARIA DECAY ON CRITICAL RESPIRATION CHARACTERISTICS

The question arises whether developing *Alternaria* has a part in the reversed and sluggish response of older lemons to anaerobic conditions. From the results of several experiments designed to solve this problem, it appears that it does not; in fact, the effect of visible *Alternaria* activity has proved to be the opposite. Lemons with active *alternaria* decay have always shown a speeded-up response under the conditions of the special respiration conditions employed in this investigation. This does not mean that the *Alternaria* infection has increased

TABLE 13.—Critical respiration characteristics of lemons in relation to condition of the buttons

[Terms explained on p. 26 and in legend for fig. 8]

Date stored	Storage period	Maturity of fruit when stored	Button condition	Critical characteristics			
				Duration of negative pressure (A)	Maximum negative pressure (B)	Area (C)	Slope (D)
1940				Hours	Cm. Hg	Sq. cm.	Degrees
February 6.....	3	Tree-ripe.....	Full-green.....	31	4.3	20.8	69
			Inter-green.....	36	4.1	22.1	66
June 6.....	7	Silver.....	Full-green.....	32.5	2.1	10.9	61
			Full-black.....	37	2.7	14.8	58
April 6.....	16	Light-green.....	Full-green.....	34	2.7	15.2	63.5
			Full-black.....	36	3.3	19.0	64.5
1941							
July 2.....	11	Dark-green.....	Full-green.....	25.5	1.3	4.8	68
			Inter-green.....	27	1.8	7.6	62.5
			Inter-black.....	28	2.1	9.6	65.5

the respiration rate of the lemon tissue, but that the total respiration of lemon tissue plus *Alternaria* has increased, so that *Alternaria* activity within lemons can prevent the expression of the reversed response of old lemons to anaerobic condition. Table 14 gives the principal results of a test to show the effects of *Alternaria* on the respiration. The lemons used were the combined left-overs of five different storage lots from the still-air chamber, 1939. Most of this fruit had been in storage 18 to 21 weeks, and to the date of the test 15 to 35 percent of it had shown *alternaria* decay. All buttons were black. Twelve respiration chambers were filled with these lemons, and after the respiration test the lemons were cut and arrayed according to increasing amounts of *Alternaria*. The values of the critical respiration characteristics of the three lots with the least *Alternaria* infection (6, 11, and 1) and of the three with the most (4, 2, and 12) are presented in table 14. With few exceptions the critical values of the six intermediate samples as regards *alternaria* decay fell between those of lots 11 and 4. The anaerobic respiration response of lots 6, 11, and 1 was very slow as compared with that of lots 4, 2, and 12; the total recorded response of the last group was much more rapid than the fresh fruit could have made at any time after being placed in storage.

TABLE 14.—Critical respiration characteristics in relation to *Alternaria* infection

[Terms explained on p. 26 and in legend for fig. 8]

Lot No.	Fruits infected by <i>Alternaria</i>	Duration of negative pressure (A)	Maximum negative pressure (B)	Area (C)	Slope (D)
	Percent	Hours	Cm. Hg	Sq. cm.	Degrees
6.....	0	40	3.2	19.1	60
11.....	0	34.5	2.5	13.5	57
1.....	5.2	34.5	3.1	18.9	64
4.....	21.4	16.5	1.1	2.8	67
2.....	35.0	10	1.0	1.6	65
12.....	88.0	5	.1	.2	71

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