THE EFFECT OF DIFFERENT STORAGE CONDITIONS ON SOME PHYSICAL AND CHEMICAL CHANGES IN ARIZONA CITRUS FRUIT

by

Salah E. M. Mahmoud

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INTRODUCTION

Preserving fruits is relatively an old industry which goes hand in hand with the development of civilization. Among the methods used are the following: canning, freezing, drying, and concentrating. And storage of fresh fruit is no novelty. For marketing purposes and transportation, it is of great value. This emphasizes the urgent need for improved methods of storage so that the fruit reaches the market in optimum condition.

Substances essential to the human body, such as vitamins and minerals, are found in greatest abundance in fresh, healthy fruit. For this reason preserving fresh fruit in a non-deteriorated condition is of prime importance.

The decline and deterioration of fruit after harvest can be attributed both to pathological and physiological disorders. The first are caused by fungi and bacteria which result in decay and mold. The physiological disorders are connected with the life processes of the plant cells, in which catabolism is an important factor.

Since fruit is a living plant part even after it is harvested, it is capable of carrying on its life processes to a certain extent as it did before harvest. The fruit continues its catabolic activities, accompanied by the destruction of its constituents. This is manifested in respiration, transpiration or water loss, and other physical and chemical changes occurring within the fruit.

The object then is to slow down these processes as much as possible, without entirely stopping them, in order to prevent loss of the nutritional value of the fruit. Citrus fruit is relatively perishable as compared with other fruit such as apples and pears, when held in storage. This warrants the work that has been done and is still being done to find methods for keeping citrus fruit in storage as long as possible without deterioration.

REVIEW OF THE LITERATURE

Storage of citrus fruits at different temperatures has been studied by many investigators. Experiments conducted by Hawkins and Magness in 1920 (14) with Florida fruit showed that pitting, one of the most serious troubles connected with cold storage of citrus fruit, was less serious at relatively high, cold storage temperature (about 45° F.).

More recent work by Hawkins and Barger (13) indicates that "curing" the fruit at about 70° for approximately 10 days materially reduces the amount of pitting. This comment is also made: that Marsh seedless grapefruit is not adapted for holding in cold storage.

Young and Read (32) working with Valencia and

Washington Naval oranges in Australia found that the carefully handled fruit kept much better than that handled in the ordinary way. They thought the sweating which took place during transportation added to the keeping qualities of the unwrapped fruit. They also reported little change in the sugar content of the juice during storage.

Overholser (23) working on marine refrigeration of California oranges found that temperatures of 36-38° F. were most satisfactory. Lower temperatures resulted in rind breakdown, and higher temperatures in wilting of fruit and blue mold contamination.

Friend and Bach (8), working with Texas citrus fruit, found a temperature of 45° best suited for cold storage of grapefruit and 31-32° most satisfactory for holding Valencia oranges. They were able to keep grapefruit 8-10 weeks, and oranges as long as 20 weeks.

The chemical and physical characteristics of ripe citrus fruits have received a good deal of attention, but little work has been done on the changes taking place during storage.

Hawkins and Magness (14) studied the changes in Florida grapefruit during storage, with particular attention to the sugar and acid content of the pulp or edible portion as influenced by 6 different storage temperatures. They found that the acid content decreased slightly during storage for 4 months at 32°; loss in acid rarely amounted to more than

0.2 percent. Total sugar remained about constant. At higher temperatures (55-60°, 70 and 86° F.) in some cases there was an increase in acidity and a reduction in the amount of sugar. At these temperatures there is evidence that this increase in percent acid is not due entirely to loss of water from the pulp; there is an actual increase in the amount of acid present.

They also reported that glucoside naringen, the principal bitter substance in grapefruit, decreased in cold storage. This, along with the decrease in acidity, caused an improvement in the flavor of grapefruit.

Zoller (33) found that the acid of the pulp decreased during storage, with an increase in solid/acid ratio. He records that the content of the glucoside naringin was less in the peel after storage. He apparently used only a small number of fruit in his storage experiments.

Stahl and Camp (27) with Florida grapefruit verified the results of Hawkins and Magness (14) as far as acids are concerned, but claimed total sugars increased during storage. Since mature fruit contains no starch to be converted to sugar, there is a possibility that the cell wall materials such as pectins and hemicelluloses could be hydrolyzed into sugars. They reported that Valencia oranges maintained the same trends as grapefruit in storage. There was an increase in pH value and total soluble solids in the juice, and a decrease in percent juice.

Martin (17), for Arizona grapefruit stored at 60° F. and 88 percent relative humidity, reported there was a slight increase in percent acid in the first months in storage, but continual decrease was observed with prolonged storage.

He pointed out that solid/acid ratio showed little change in the first 2-3 months, but later increased rapidly. This was caused by a more rapid decrease in citric acid than in soluble solid, possibly related to a preferential use of the acid in respiration. He noted that fruit had lost volume more rapidly than weight. Loss in weight amounted to 3-4 percent after 8 weeks in storage at 60° and 88 percent relative humidity. There was an increase in percent juice as a result of shrinkage of the rind. Color of the rind deepened with storage, and off flavors developed in some cases, but usually not before 3 months. He mentioned, however, that some lots of early picked fruit were held as long as 6 months, maintaining fair condition and flavor.

In recent years there has been considerable interest in vitamin C changes in fruit during storage. According to reports from several sources (10, 31), oranges showed no significant losses in vitamin C when held as long as 2 weeks to 3 months.

Moore and Wiederhold (21) reported that canned orange juice retained 81.7 and 95.1 percent of the initial ascorbic acid after 6 months storage at 80° and 40° F., respectively.

French and Albot (7) pointed out that vitamin C of oranges and grapefruit may increase during the first few weeks of cold storage, then drops off slowly. No great amount of work has been done on storage of the tangerine.

In Brately's study (2) of Dancy tangerine in the New York market, fruit was held for 8 weeks at temperatures of 32-33°, 36-38°, 45-48°, and 53-55° F. He mentioned that there was a marked loss in total acid and vitamin C during storage at all temperatures, accompanied by a rise in pH value. These losses were greater at the higher temperatures.

Chemical analysis of California lemons stored at 32-60° gives an idea of some of the changes occurring. Miller and Schomar (20) found that total sugar decreased in both peel and pulp during 15 weeks in storage.

Experiments conducted in South Africa (6) on lemons show more juice, soluble solid, and acid in fruit held at 50° than at other temperatures (40, 45 and 55° F.), providing the fruit was mature but still green in color when put into storage and when held for 4 months.

Harvey (11), experimenting with California lemons, pointed out that during storage there is a reduction of the materials which are extractable by cold water or sulfurous acid. The compounds in question no doubt are those contained in the cell walls, such as pectins and hemicelluloses.

Delft (5) stated that the antiscorbutic value of lemons remains unimpaired as long as fruit remains in good condition.

Miller (18) concluded that citrus fruit, if held at high temperature, is attacked by microorganisms and undergoes some physical and chemical changes which impair attractiveness and palatability. At these temperatures, fruit loses much of its nutritional value due to loss of acids, solids and other compounds which impair flavor and aroma. He pointed out that retarding these changes is accomplished by cold storage. Each variety has a suitable temperature at which it may be stored with the fewest changes. He suggested storing grapefruit at 45-55° where stem end decay is not a factor, but at 32° where stem end is a factor. Thus fruit can be held 6-8 weeks and remain in good condition. For oranges he suggested 34-38° for 8-10 weeks, and for lemons 55-58° F. for 1-4 months.

Loss in weight, physiological disorders, and pathogenic infestation are other problems encountered in storage of citrus fruit. While the amount of loss in weight and extent of decay are closely related to high temperatures, physiological disturbance is connected with low temperatures (27).

Pitting is a cold storage disease, due probably to suboxidation and a consequent accumulation of toxic substances (22). Some of the other diseases connected with cold storage are scald, soggy breakdown, membranous stain, peteca, red blotch, and albedo browning (3, 22, 26). Stem end rot, alternaria decay, blue and green molds are important pathogenic infestations in storage (26).

In partial attempts to retard loss in weight, many kinds of fruit wrappers have been tried. Wrapping tissue is more commonly employed for holding citrus fruits in cold storage.

Hendrickson (15) found that tissue wrappers were unsatisfactory as they prevented little moisture loss and became entirely soaked within a few hours after removal from storage. Wrapped fruit developed pitting as well as fruit without wrapping.

Tindale (30) showed that Washington Naval oranges, when wrapped, remained in a firm condition and the formation of mold "nests" was prevented.

Brown (4) mentioned that waxed paper reduced moisture loss from certain vegetables, but that decay was greater. He noted that paper wrappers had some cushioning value which helped protect perishable products from mechanical injury. No increase in acidity either as pH or titratable acidity could be detected in tomatoes as a result of wrappers.

In the past several years many types of moisture-proof wrappers have been placed on the market, among which are cellulose acetate products and rubber hydrochlorides; both are transparent films. Stahl and Fifield (28) showed the superiority of moisture-proof wrappers for the preservation of citrus fruits in storage. The storage life of fruit varies greatly with the materials used.

Pliofilm (a synthetic plastic containing rubber hydrochloride as its principal base) is being used for many manufactured food products. Little investigation has been published on pliofilm used on fruit.

Stahl and Vaughan (29) reported that pliofilm was effective in retarding the weight loss of citrus fruit, without limiting the escape of the respiratory gases evolved from the fruit. Their data on round oranges, mandarin oranges, and grapefruit showed that original weight, color, texture, and flavor were well maintained in pliofilm. Loss of initial size and firmness (shrinkage) was proportional to the percentage weight loss; pliofilm-wrapped fruit lost about one-tenth or less as much as did unwrapped fruit.

Stahl and Vaughn also mentioned that pitting was prevented almost entirely by pliofilm. The fruit held in pliofilm proved to be much superior in taste and appearance to that unwrapped or tissue-wrapped. There was no significant difference in percentage of fruit lost through decay in pliofilm-wrapped and unwrapped fruit. Pliofilm, however, did prevent nesting.

Scott and Tewfic (24) noted that pliofilm permitted the accumulation of an abnormally high CO_2 content, which impaired the flavor of certain susceptible kinds of produce.

MATERIALS AND METHODS

Conditions of Experiment

Five varieties of citrus fruit were used in this study. The experiment was begun in May, 1949 with Marsh seedless grapefruit and Valencia oranges of the spring crop. The work was resumed in November and December 1949 with Marsh seedless grapefruit, Naval oranges, Algerian tangerines, and Eureka lemons of the fall crop.

The grapefruit, Valencia orange and Eureka lemon were obtained from groves of the Yuma Mesa citrus experiment farm. Fruits were given the standard dry-wax brush treatment and packed in the standard commercial method as Sunkist grade.

Naval oranges were obtained from the Mesa district, Salt River Valley. Fruit was treated with borax followed by wax spray, and packed as Sunkist grade.

Algerian tangerines were obtained from the Yuma Mesa Experiment Farm. Fruits, harvested by the standard procedure of clipping with two leaves attached, were immediately packed in pliofilm bags in the orchard.

At no time was the interval between picking and storing more than three days--the time required for packing and shipment--with the exception of the tangerine where only one day elapsed between picking and storing.

Fruit was put in three kind of containers and immediately placed in the storage rooms. The three methods of storage were:

1. Fruit held in ordinary mesh bags
2. Fruit tissue-wrapped and held in mesh bags
3. Fruit held in pliofilm bags, with a rubber band used to close the bag.

The fruit was stored in Tucson, Arizona and held at 4 different temperatures: 40, 50, 70° and room temperature. In most cases temperatures fluctuated within the limits of 2° F. with the exception of room temperature, where the fluctuations were greater.

The refrigeration room of W.H. Cox & Sons, fruit and vegetable warehouse, was used to represent storage temperature of 40°, with a relative humidity of 85 percent. The University of Arizona dairy laboratory refrigeration room was used to represent 50° F. with relative humidity of about 88 percent. While the cotton laboratory at the University was used to represent 70° with relative humidity of about 65 percent.

The horticultural laboratory at the University was used to represent room temperature. This meant an average of 84° in the spring and summer months, and 77° for the fall and winter months, with an average relative humidity of about 57 percent.

Each variety of fruit was stored at the 4 different temperatures and in the 3 different containers, and was held for varying lengths of time. Bags were stacked next to each other on shelves, as shown in Figure I, at all temperatures except 40° F. where they were stacked on boxes.

Methods of Analysis

Methods of analysis were the same for all samples. In each analysis one sample of 5 fruit was used, with the exception of the Valencia orange where 10 fruits were used.

Marsh seedless grapefruit and Valencia oranges of the spring season 1949 were analyzed regularly at 2-week intervals and the weights recorded at 10-day intervals.

Marsh seedless grapefruit, Naval orange, Algerian tangerine and Eureka lemon of the fall season 1949 were analyzed at 3-week intervals. Weights were recorded at weekly intervals, and separate samples consisting of 20 fruits each were held for this purpose.

Molded and contaminated fruit was removed whenever it was found.

Fruit diameters, both axial and equatorial, were measured in millimeters by using a ruler and triangle. Each sample was weighed before and after storage. Volume of fruit was determined by water displacement.

In all chemical tests, the fruit was halved, thickness of peel measured in millimeters from both sides, and the juice extracted from both halves by means of a hand reamer. Attention was paid not to extract the oil of the peel with the juice. Volume of juice was then measured in milliliters

Figure I. A view showing the method of stacking bags on shelves in the storage rooms.

by means of a glass graduate.

All values taken were divided by the number of fruits to get the average value of one fruit.

The following chemical analyses were then made on the extracted juices:

1. Titratable acidity was obtained by titrating 10-cc. samples of the juice with N/10 sodium hydroxide, using phenol-phtalein as the indicator.

2. Since there is a high correlation between total soluble solid and total sugar in citrus juices--in other words, since sugar constitutes a considerable percentage of the total soluble solid--instead of sugar determination, total soluble solid was determined by means of a refractometer. Thus percent soluble solid is obtained and ratio solid/acid calculated.

3. Ascorbic acid (vitamin C) was determined by the method of Lucas (16). This is essentially the oxidation of ascorbic acid quantitatively with 2, 6-dichlorophenolin-dophenol. This is accomplished by titrating 1-cc. samples of fruit juice with the dye solution, using 3 percent HPO_3 as a titratable medium.

4. pH value was determined by the Beckman glass electrode.

Color of both fruit and juice, the taste, decay and physiological disorders were observed during the experimental work. Color determinations were made with the help of the Color Standards of Mertz and Paul.

PRESENTATION OF RESULTS

Results with Marsh Seedless Grapefruit

The storage data for Marsh seedless grapefruit of the fall season are presented with similar data for fruit of the spring crop. Results of changes occurring during storage are obtained from analysis of the fruit at 3-week intervals. The fruit was put in storage in November, 1949 and was held for 12 weeks.

Physical Changes During Storage

Loss in weight: Loss in weight of grapefruit always accompanied storage. Table I shows the original weight before storage and summarizes percent loss after different periods at various temperatures. It also throws light on the rate of loss in weight as affected by different containers. The table brings out clearly that most of the loss occurred within the first 3 weeks, and a gradual decrease took place after that time. The higher the temperature, the more loss in weight, with practically no difference between fruit stored at 40 and 50°. However, the difference was pronounced between the lower temperatures and 70°, and also between 70 and room temperature of 77° F. The differences between weight losses occurring at 70 and 77° are due to the difference in temperatures and humidity; at 70° the humidity is 65 percent, and at room temperature 57 percent.

TABLE I

LOSS IN WEIGHT OF MARSH SEEDLESS GRAPEFRUIT

Temper-ature	Wks. in storage	Weight before storage (gms.)**			Percent loss in weight		
		M*	Wr+	P#	M*	Wr+	P#
40° F.	3	384	364	374	6.50	5.80	1.87
	6	342	367	356	6.73	5.74	1.40
	9	360	385	352	8.60	7.30	1.70
	12	362	396	377	10.20	8.10	1.59
50° F.	3	366	362	372	6.84	6.35	1.88
	6	346	386	377	7.80	5.97	1.59
	9	377	382	354	7.45	8.12	2.26
	12	361	366	354	10.25	9.30	2.26
70° F.	3	360	384	371	12.50	10.70	2.97
	6	360	381	368	20.60	17.30	4.10
	9	374	398	398	30.60	32.00	10.50
	12	365	375	345	32.60	32.80	8.13
77° F. (room)	3	375	375	346	21.00	17.30	4.35
	6	382	390	362	31.80	27.50	7.46
	9	388	392	363	38.80	39.00	11,85
	12	368	382	360	42.00	44.50	14.15

**Average of 5 fruits
*Fruit unwrapped and held in mesh bags
+Fruit paper-wrapped and held in mesh bags
#Fruit held in pliofilm bags

While fruit stored at 40° lost about 6.5 percent in weight after 3 weeks, that stored at 70° lost 12.5 percent. In other words, at this high temperature fruit lost about twice as much as at the low temperature.

Table I and Figure II show clearly the marked effect of pliofilm in preventing rapid weight loss evident in paper wraps and mesh bags at any storage temperature. The rate in loss of weight of fruit held in mesh bags was at least five times that of fruit held in pliofilm bags. In other words, pliofilm reduced the loss in weight to one-fifth, or even less, of that in mesh bags. Standard tissue wraps helped in preventing weight loss but was much less efficient in comparison with pliofilm.

Figure II brings out very clearly that weight loss is dependent on temperature, kind of container, and length of storage period. Most of this weight loss was due to loss in moisture. However, some may be lost by respiration and other catabolic activities of the living fruit.

Loss in weight was accompanied by some other physical changes. There was a progressive decrease in fruit volume (cc. per 100 gms. of original weight), peel thickness and fruit diameters, both axial and equatorial. The higher the temperature, the greater decrease in these values took place, especially when the atmosphere was dry. This was indicated by the more pronounced drop in fruit volume at room temperature with low relative humidity when compared with 70° F. and

TABLE II

SOME PHYSICAL CHANGES IN MARSH SEEDLESS GRAPEFRUIT AS AFFECTED BY KIND OF CONTAINER AND LENGTH OF STORAGE PERIOD**

	Fruit volume %++			Peel thickness (mm.)			Axial diameter (mm.)			Equatorial diam. (mm.)		
Before storage	135.0			9.5			88.8			96.4		
Wks. in storage	M*	Wr+	P#	M*	Wr+	P#	M*	Wr+	P#	M*	Wr+	P#
				Stored at 40° F.								
3	123.0	123.0	135.0	9.0	8.5	10.0	92.2	86.4	92.0	95.0	94.3	97.4
6	121.0	132.0	134.5	8.0	8.5	10.5	84.0	90.0	92.2	88.6	91.4	95.2
9	119.0	125.0	137.0	7.0	8.5	10.5	85.6	88.5	91.6	91.0	94.0	96.0
12	114.0	125.0	134.0	7.5	8.0	9.5	84.2	87.0	91.0	92.0	94.0	95.2
				Stored at 50° F.								
3	120.0	132.0	140.0	8.5	10	10.0	85.8	89.0	94.2	96.2	97.6	98.2
6	122.0	129.0	137.0	8.0	8.6	9.0	87.2	91.0	92.0	94.6	95.8	97.2
9	122.0	128.0	135.0	8.5	8.5	9.5	88.8	90.0	92.8	90.4	95.2	96.0
12	118.0	128.0	135.0	8.0	8.0	9.5	87.2	88.8	88.8	85.4	94.6	97.0
				Stored at 70° F.								
3	118.0	120.0	135.0	7.5	8.0	10.0	85.6	88.2	83.6	91.2	94.4	98.2
6	108.0	115.0	133.0	6.6	8.2	9.0	84.6	87.4	86.0	87.8	92.0	97.2
9	86.0	112.0	123.0	5.0	7.0	8.5	78.2	82.2	89.4	84.8	91.0	96.8
12	78.5	82.0	125.0	3.8	5.0	8.5	72.8	77.0	89.0	84.0	83.2	91.2

TABLE II (cont.)

Wks. in storage	Fruit volume %++ M*	Wr+	P#	Peel thickness (mm.) M*	Wr+	P#	Axial diameter (mm.) M*	Wr+	P#	Equatorial diam. (mm.) M*	Wr+	P#
Before storage	135.0			9.5			88.8			96.4		
Stored at 77° F. (room)												
3	97.0	113.0	133.0	5.5	7.0	9.0	81.6	83.4	89.0	88.0	88.0	94.4
6	78.0	92.0	126.0	3.4	5.6	8.8	74.6	81.8	88.2	82.4	88.6	93.8
9	72.0	77.0	133.0	4.0	4.0	9.0	74.2	74.8	91.6	81.2	81.4	95.2
12	74.0	74.5	113.0	3.5	4.0	8.5	75.4	74.4	86.0	79.8	80.2	90.6

**Values are the averages of 5 fruit
++Basis of 100 gms. of original weight
*Fruit unwrapped and held in mesh bags
+Fruit paper-wrapped and held in mesh bags
#Fruit held in pliofilm bags

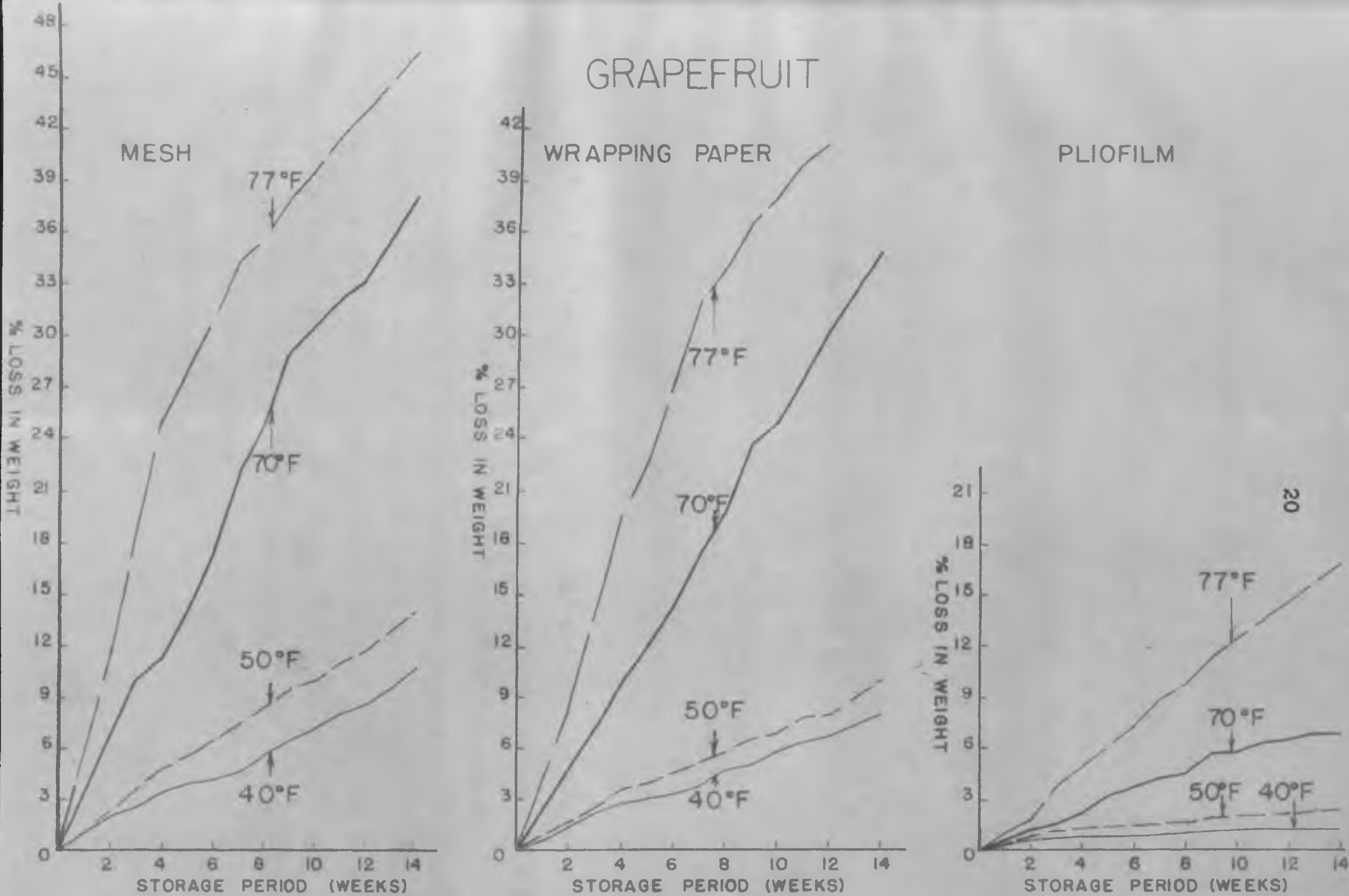

FIG II PERCENT LOSS IN WEIGHT IN MARSH-SEEDLESS GRAPEFRUIT STORED AT VARIOUS TEMPERATURES IN DIFFERENT CONTAINERS AS AFFECTED BY THE LENGTH OF STORAGE PERIOD.

higher relative humidity after 3 weeks in storage (see Table II).

Peel thickness showed an appreciable difference between the higher and lower temperatures. Fruit diameters also showed a difference, but at a less pronounced rate.

Comparing the three different containers, pliofilm gave the most satisfactory results in slowing down the rate of decrease in these values. Practically, fruit held in pliofilm at lower temperatures (40 and 50°) did not show any appreciable change in these values during the entire storage period. However, fruit size, peel thickness, diameters, and appearance of fruit were greatly affected by loss in moisture.

Shriveling always accompanied excessive drying. Not only the rind lost moisture, but the pulp and juice also dried out. This is manifested by the progressive decrease in percent of juice (ml./100 gms. of original weight). Table III shows the effect of different storage temperatures and containers on the decrease in juice with prolonged storage; it is obvious that the lower the temperature, the less decrease took place. The most loss in juice occurred within the first 3 weeks in storage, with little decrease in successive weeks. Pliofilm was superior to tissue wrap in preventing loss in juice constituents. Fruit held in ordinary mesh bags lost juice more than that in any of the other containers used.

TABLE III

EFFECT OF TEMPERATURE AND KIND OF CONTAINER ON PERCENT JUICE OF MARSH SEEDLESS GRAPEFRUIT

(Percent juice per 100 gms. of original weight)
Before storage 43.0

Wks. in	40° F.			50° F.			70° F.			77° F. (room)		
storage	M*	Wr+	P#	M*	Wr+	P#	M*	Wr+	P#	M*	Wr+	P#
3	38.6	42.0	41.5	39.0	40.0	40.5	40.5	41.0	41.5	36.3	38.0	40.5
6	37.0	39.6	41.0	41.0	42.5	43.0	39.0	40.5	40.5	32.8	37.8	40.5
9	35.0	37.0	40.5	41.0	41.5	42.0	40.5	37.8	38.8	29.4	37.2	42.0
12	38.0	40.5	42.0	40.5	39.2	41.0	38.4	36.0	41.0	30.3	31.7	40.5

*Fruit unwrapped and held in mesh bags
+Fruit paper-wrapped and held in mesh bags
#Fruit held in pliofilm bags

The percentage of juice increased as the storage period advanced. This can be understood since fruit loses volume (due to loss in moisture from the peel) more rapidly than it loses juice; consequently the percentage of juice increases.

Chemical Changes in Storage

The chemical components and their biochemical relationships can be interpreted, in part, in terms of the edible quality of fruit. It is important to investigate the changes that occur in the soluble constituents of the juice during storage to correlate the concentration of one soluble constituent with that of another, for the purpose of determining their physiological and chemical relationships.

Chemical data obtained from analysis of Marsh seedless grapefruit showed less pronounced changes as compared with such physical changes as weight, volume, etc. However, some of the values were pronounced enough to show the general trend.

There was a progressive increase in percent acid (mgs. per 100-cc. of juice) as the storage period lengthened and as temperature went up, causing the development of acid taste. Fruits held in pliofilm bags had less percent acid than that held in other bags. There was practically no appreciable difference in percent acid between tissue-wrapped fruit and that held in ordinary mesh bags. In other words, the difference can be within the limits of experimental error and variation in content among individual fruits.

Table IV summarizes the acid percentages of fruit stored for different periods in different temperatures and containers. It is noticed that while percent acid was 1.61 (mgs. citric per 100 cc. juice) before storage, it was 2.36 and 2.03 percent, respectively, in fruit held at 70° and at room temperature after 12 weeks in storage when held in mesh bags.

This increase in acidity was not an actual increase in quantity, which showed a decrease by respiration; the increase in acidity is apparently due to concentration resulting from the progressive dehydration of the juice. This is quite obvious, since there was a correlation between loss in moisture and increase in acidity. In other words, factors which accelerated dehydration, also accelerated the increase in acid percent.

While titratable acidity showed a progressive increase during storage, there was practically no change in pH value. The difference was not more than .2 between the maximum (3.3) and the minimum (3.1). See Appendix A. And this slight difference is due presumably to the variation among individual samples. In this study it is presumed that pH value remained about constant.

Percent soluble solid was found to increase during storage, the amount of increase being correlated with temperature; the higher the temperature, the more increase in

TABLE IV

CHANGES IN PERCENT ACID OF MARSH SEEDLESS GRAPEFRUIT
(Percent acid (mg. citric per 100 cc. juice)

Wks. in storage	Before storage 1.61		
	M*	Wr+	P#
	Stored at 40° F.		
3	1.65	1.85	1.83
6	1.82	1.67	1.67
9	1.72	1.63	1.65
12	1.98	1.81	1.71
	Stored at 50° F.		
3	1.77	1.91	1.79
6	1.66	1.78	1.49
9	1.80	1.66	1.58
12	1.82	1.66	1.59
	Stored at 70° F.		
3	1.87	1.84	1.78
6	1.84	1.73	1.61
9	1.89	1.80	1.70
12	2.36	1.94	1.75
	Stored at 77° F. (room)		
3	1.90	1.90	1.79
6	1.66	1.74	1.56
9	1.80	1.89	1.80
12	2.03	1.98	1.75

*Fruit unwrapped and held in mesh bags
+Fruit paper-wrapped and held in mesh bags
#Fruit held in pliofilm bags

percent soluble solid took place. At the lower temperatures (40 and 50°), the increase during the first few weeks in storage was followed by a decrease with prolonged storage. This decrease did not show up in fruit held at high temperatures. This is particularly true with paper-wrapped fruit and that held in mesh bags. The least increase in percent soluble solid occurred in fruit held in pliofilm bags, which remained practically constant at lower temperatures and showed a more pronounced increase at higher temperatures.

Table V summarizes changes in percent soluble solid taking place in storage at different temperatures and different containers.

The increase in soluble solid percent is definitely a result of the progressive loss in moisture from the juice and consequent concentration of solid materials per unit volume of juice. The more the fruit lost moisture, the more the solid increased in percent. Should percent solid be calculated per 100 grams of original weight, it showed a decrease during storage. The higher the temperature, the more loss in soluble solid took place. The rate of decrease was affected by the kind of container used; the least loss was found to be in fruits held in pliofilm bags.

This decrease in soluble solid can be easily understood by remembering that fruit is a living plant part. It maintains its catabolic activities and life processes on the food materials stored within it; hence the metabolic activity

TABLE V

CHANGES IN PERCENT SOLUBLE SOLID AND SOLID/ACID RATIO OF MARSH SEEDLESS GRAPEFRUIT

Wks. in storage	% soluble acid++ M*	% soluble acid++ Wr+	% soluble acid++ P#	Ratio solid/acid M*	Ratio solid/acid Wr+	Ratio solid/acid P#
Before storage		10.07			6.27	
	Stored at 40° F.					
3	11.06	11.4	10.90	6.72	6.20	6.00
6	11.12	10.73	10.73	6.13	6.44	6.44
9	10.73	11.38	10.73	6.26	6.99	6.53
12	10.40	10.73	10.73	5.27	5.95	6.30
	Stored at 50° F.					
3	11.30	11.50	10.73	6.40	6.00	6.00
6	11.90	10.60	10.80	6.70	6.85	7.25
9	10.73	11.12	10.73	5.99	6.72	6.80
12	10.73	10.87	10.13	5.90	6.55	6.40
	Stored at 70° F.					
3	12.10	11.06	11.94	6.50	6.02	6.72
6	12.31	11.90	11.12	6.71	6.91	6.92
9	12.00	11.80	10.80	6.35	6.55	6.37
12	11.88	12.00	11.20	5.05	6.20	6.40
	Stored at 77° F. (room)					
3	12.00	12.30	11.31	6.30	6.50	6.30
6	11.88	12.00	11.94	7.16	6.90	7.67
9	12.06	13.36	11.38	6.70	7.07	6.32
12	11.88	12.69	11.38	5.85	6.40	6.50

++Basis of 100 cc. juice
*Fruit unwrapped and held in mesh bags
+Fruit paper-wrapped and held in mesh bags
#Fruit held in pliofilm bags

is entirely a destructive one. This, of course, includes respiration which is the chemical process of breaking down the organic materials with a release of energy used to maintain life. The main source of the organic food needed is the total soluble solid. No wonder, then, that the soluble solid showed a decrease during storage, depending on the rate of life activities of the fruit, which were slowed down by low temperatures and enhanced by high temperatures.

Table VI shows changes in percent soluble solid calculated per 100 grams of original fresh weight of fruit held in mesh bags and stored at 40 and 77° F. It can be noted that, while there was no appreciable loss in solid percent during the first 6 weeks at 40°, the loss was accelerated during the following weeks in storage. Pliofilm had a slowing effect on the life processes and consequently there was less loss in soluble solid, probably because the film allows some accumulation of CO_2 gas and hence less respiratory activity (24).

Ratio solid/acid showed slight change in storage. However, fruit held in mesh bags showed a slight increase in the ratio within the first few weeks in storage, followed by a decrease at the end of the 12 weeks.

Fruit held in pliofilm showed a slight increase in the ratio. It was slightly higher for fruit held in pliofilm bags than for that held in other containers. This is due to the lower acid percent of the fruit, fortified by the

TABLE VI

PROGRESSIVE CHANGES IN PERCENT SOLUBLE SOLID OF MARSH SEEDLESS GRAPEFRUIT HELD IN MESH BAGS

Wks. in storage	Percent soluble solid (Basis of 100 gms. original weight) Before storage 4.25	
	40°	77°
3	4.25	4.25
6	4.50	3.78
9	3.76	3.54
12	3.95	3.60

development of a relatively flat taste which always accompanied holding fruit in pliofilm.

The nutritive quality of the stored fruit in terms of vitamin content is an important point to consider. Although these data are from too limited a sample for statistical formulae, there are certain indications concerning ascorbic acid changes in fruit during storage.

Vitamin C showed a slight decrease when calculated in terms of milligrams per 100 grams original weight. The higher the temperature, the most loss in vitamin C occurred. There was no significant difference in vitamin C content between fruit held at 40° and that held at 50° F. Table VII summarizes percent vitamin C in fruit held at 40 and 77° F.,

TABLE VII

PROGRESSIVE CHANGES IN VITAMIN C PERCENT
OF MARSH SEEDLESS GRAPEFRUIT

Wks. in storage	Percent vitamin C (ascorbic acid) (Basis of 100 grams of original weight++) Before storage 17.80			
	40^{0}		77^{0}	
	M*	P#	M*	P#
3	16.5	17.4	15.6	16.6
6	16.5	17.0	15.0	16.7
9	16.3	16.0	14.8	16.5
12	15.9	17.0	13.0	16.4

++Mgs. per 100 gms. original weight
*Fruit unwrapped and held in mesh bags
#Fruit held in pliofilm bags

since the changes at these two temperatures were enough to exceed the variations among individual samples. It also shows a comparison between pliofilm and mesh bags in preserving the vitamin C percent. While the vitamin percent was 17.8 (mgs. per 100 gms. original weight) before storage, it became 13 and 16.4 percent, respectively, in fruit held in mesh bags and pliofilm bags after a period of 12 weeks at 77° F. (room temperature).

When calculating vitamin C percent on the basis of milligrams per 100 cc. juice, it showed no appreciable change throughout the storage period (see Appendix B). It seems that while vitamin C is lost by oxidation, the part remaining is concentrated by loss in moisture. This concentration hinders the manifestation of the actual loss in vitamin taking place, so that in percent it remained about constant. This is true at low temperature as well as high. In other words, the higher rate of loss of the vitamin constituents was proportional to its concentration in the juice and thus did not show any appreciable decrease in percent.

Miscellaneous Observations

Changes in taste and flavor were much more pronounced than those in composition. It appears that methods of analysis used were not fine enough to show much difference in composition, which was clearly brought out by taste. A storage taste was detected in fruit held at higher temperatures long before that held at lower temperatures, yet the composition showed relatively little difference. The figures are of value because they show that the changes in acid and soluble solid were slow during storage.

In general, fruit held in mesh bags and that wrapped, developed an acid taste. That held in pliofilm tended to develop a flat taste. The higher the temperature the more the taste was affected. At the end of the 9- and 12-week storage periods, taste was seriously affected by the development of bitterness and staleness. At lower temperatures this disintegration in taste was almost undetectable. Bitterness is probably due to the concentration of glucoside naringin (the bitter principal in grapefruit) as a result of excessive dehydration. The development of stale flavor is a result of the waste and by-products of respiration expelled into the atmosphere, which soon becomes contaminated by CO_2 and other by-products and deficient in oxygen. This condition is unfavorable in maintaining proper life balance, and so is followed by the production of stale taste.

There was no substantial change in color of juice, but as the fruit became dried and shriveled in appearance it developed a duller rind shade, especially when the fruit had lost much of its moisture.

Appearance of fruit was greatly affected by loss in moisture. Shriveling and drying-out started in the stem end as early as 3 weeks at 70°; the fruit lost its firmness and became soft by the 6th seek, then became almost hard about 2 weeks later. These stages of drying-out started earlier and at a more pronounced rate at room temperature; were much more delayed by lower temperatures and the use of pliofilm bags, in which hardening did not result even by the end of the 12-week period. The reason why the stem end was more susceptible to wilting than the rest of the fruit is due to the greater quantity of albedo tissue, which is said to be more responsive than the flavedo (18).

Pitting: This is a physiological disturbance which arises at low temperatures. The storage temperature of 40° is the only one used in this experiment which caused pitting. It started to appear as a few sunken spots confined to the flavedo after 3 weeks, with an increasing amount during the successive weeks. By the end of 5 weeks, the pits enlarged and coalesced, forming irregular-shaped, brown patches. Fruits were enough pitted to be unmarketable. By the end of the storage period, the fruit was almost covered with brown sunken spots.

Wrapping paper helped in postponing pitting. It did not succeed in delaying pitting more than one week, however. Fruit held in pliofilm bags did not develop pits before the 6th week, with an increasing amount during prolonged storage. Pliofilm, besides its effect in decreasing the severity of pitting, almost doubled the time required for initial showing of pits.

Figure III shows a comparison among temperatures and containers relative to development and severity of pitting and the outside appearance of Marsh seedless grapefruit after 4 months in storage.

Pathogenic decay: While physiological disorders predominated in fruit stored at lower temperature, pathological infestations predominated in fruit stored at higher

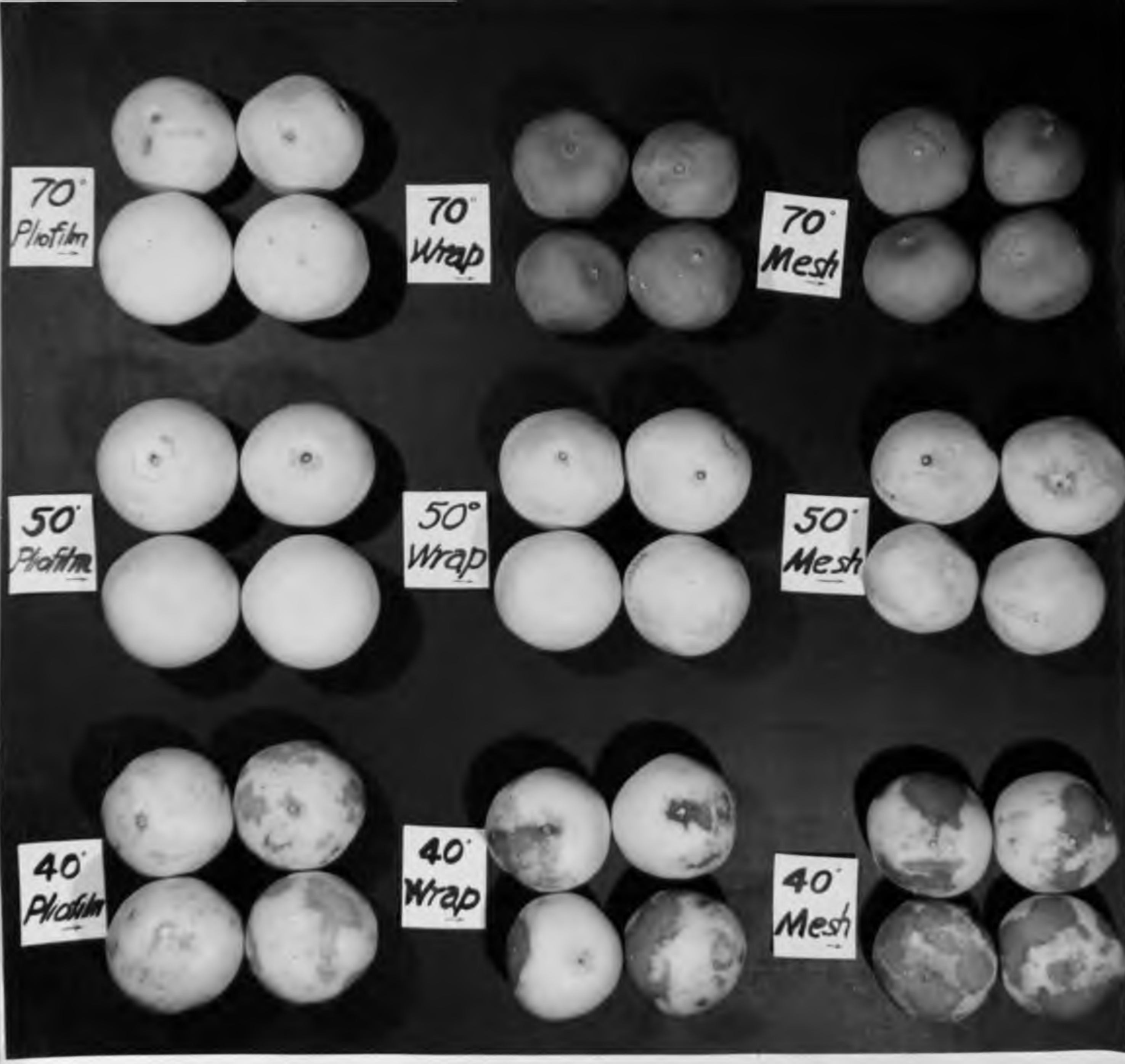

Figure III Marsh seedless grapefruit after four months in storage at different temperatures and in different containers.

Notice (a) pitting (lower) as a limiting factor for cold storage,

(b) dehydration (upper) as a limiting factor for warm storage,

(c) shriveling of the stem ends.

temperatures. The only physiological trouble at higher temperatures is the aging of fruit with consequent breakdown in rind.

The appreciable decays encountered during the course of this experiment were penicillium molds, both green and blue. Few fruits showed also stem end rot, but not so pronounced as penicillium molds. There was a decided correlation between severity of decay and high temperature, especially with high relative humidity. At the lower temperatures (40 and 50° F.) there was very little decay; at 70°, the fruit showed more decay than at 77° due to the substantial difference in humity (65 percent in the former and 57 in the latter).

Kind of container also was an important factor in development of decay. It was serious in fruit held in pliofilm, which retains the humidity transpirted by the fruit and so furnishes a good medium for the fungi. Had the fruit been treated with fungicides or any of the other sanitary precautions, the results might have been changed materially.

Results with Valencia Orange

The work with Valencia oranges of the spring crop was started in May, 1949. Samples were placed in storage, and complete analysis was made on the fruit every 2 weeks until the termination of the experiment at the end of 8 weeks.

Physical Changes

Loss in weight: A study of Table VIII shows clearly the effect of temperature and kind of container on weight loss. It is readily seen that the higher the storage temperature, the greater the loss in weight. It was found that fruit lost most of its weight during the first 2 weeks in storage, with a gradual loss generally during the successive periods. While fruit held at 40° F. lost 3.76 percent of its weight after 2 weeks, that held at 70° lost 9.6, or about three times as much, when held in mesh bags.

Mesh-bagged fruit lost about 5-6 times as much weight as pliofilm-bagged at lower temperatures, and about 9-10 times as much at higher temperatures. Wrapping papers helped prevent weight loss to some extent.

Figure IV shows the losses in weight of Valencia oranges. It is quite obvious that the kind of bag was as important, or even more so, as in storage temperature in preventing weight loss.

In addition to the decrease in total weight, there was a pronounced decrease in the other physical characteristics of the fruit. Volume (per 100 gms. of original weight) decreased with prolonged storage, though most of this loss occurred within the first 2 weeks. While the decrease in volume was very obvious in mesh bags, it was less evident in tissue wrap and even less in pliofilm bags. Or at least the decrease in volume of fruit in pliofilm was not enough to manifest

TABLE VIII

LOSS IN WEIGHT OF VALENCIA ORANGE

Temperature	Wks. in storage	Weight before storage (gms.)**			Percent loss in weight		
		M*	Wr+	P#	M*	Wr+	P#
40° F.	2	159.5	none	164.0	3.76	none	0.61
	4	168.5	none	169.5	6.25	none	1.18
	6	171.0	172.0	161.0	7.00	6.70	1.24
	8	163.5	160.0	171.0	9.50	9.70	1.20
50° F.	2	169.5	none	172.0	4.10	none	1.16
	4	172.5	none	167.5	4.90	none	0.89
	6	171.0	169.5	166.0	7.60	7.70	1.20
	8	176.0	168.0	165.5	10.80	5.65	1.51
70° F.	2	166.5	none	168.5	9.60	none	1.48
	4	153.5	none	167.5	16.30	none	2.70
	6	175.5	166.5	167.0	22.00	20.30	6.00
	8	175.5	166.5	167.0	26.00	28.50	4.20
84° F. (room)	2	171.5	none	164.5	11.40	none	2.12
	4	160.0	none	167.5	22.00	none	4.50
	6	168.0	171.0	170.0	34.00	22.80	7.65
	8	168.0	165.5	170.0	35.80	35.40	10.00

**Average of 10 fruits
*Fruit unwrapped and held in mesh bags
+Fruit paper-wrapped and held in mesh bags
#Fruit held in pliofilm bags

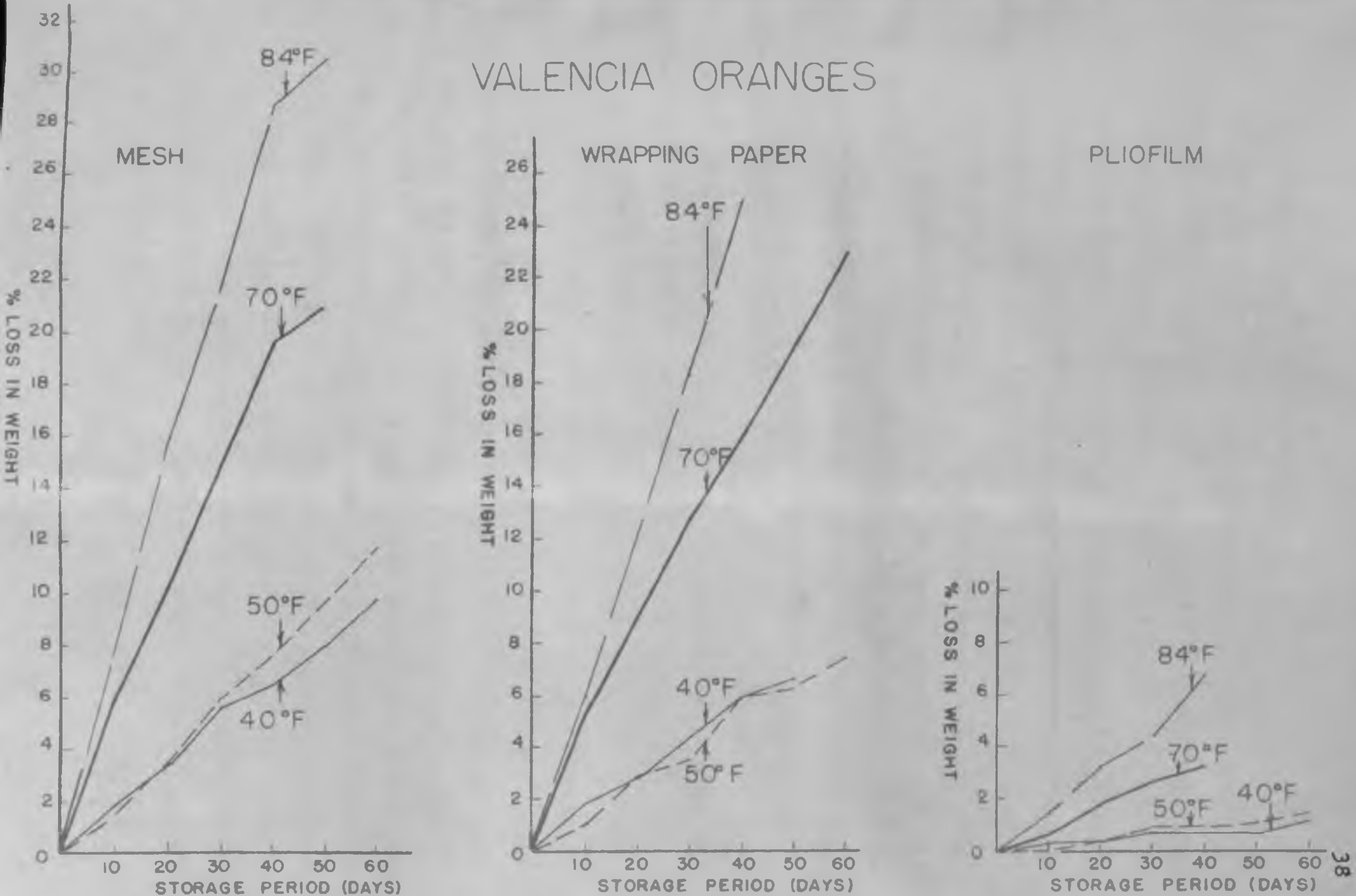

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FIG IV PERCENT LOSS IN WEIGHT IN VALENCIA ORANGES STORED AT VARIOUS TEMPERATURES IN DIFFERENT CONTAINERS AS AFFECTED BY THE LENGTH OF STORAGE PERIOD.

itself over the variations among the individual samples. The temperature had a decided effect on the amount of volume decrease. While the drop was relatively sharp in fruits stored at room temperature (84° F.), with that stored at 70° ranking next, the drop at lower temperatures (40 and 50°) was relatively slight.

Thickness of peel also decreased, due to loss in moisture and the consequent thinning of peel, especially at the higher temperatures. While both albedo and flavedo layers were about 5 mm. thick before storage, they became as thin as 1.5 mm. by the end of 12 weeks at room temperature in fruits held in mesh bags.

Fruit diameters also showed a decrease, the amount being proportional in every respect to loss in moisture (see Table IX).

In addition to decrease in the outer parts of fruit, there was a progressive decrease in juice content. Table X gives figures for percent of juice (calculated per 100 gms. of original weight) at different temperatures and in the various containers. It clearly shows that this percent juice has maintained the same direction as did the other physical changes. The loss in juice is due to the progressive dehydration and loss in moisture from the inside of the fruit. If percent juice were expressed in terms of fruit volume at time of analysis, it would show an increase during storage because of a more rapid rate in loss of volume than of juice.

TABLE IX

SOME PHYSICAL CHANGES IN VALENCIA ORANGE AS AFFECTED BY KIND OF CONTAINER AND LENGTH OF STORAGE PERIOD**

	Fruit volume %++			Peel thickness			Axial diameter			Equatorial diam.		
Before storage	112.0			5.3 (mm.)			72.0 (mm.)			65.0 (mm.)		
Wks. in storage	M*	Wr+	P#	M*	Wr+	P#	M*	Wr+	P#	M*	Wr+	P#
				Stored at 40° F.								
2	108.0	none	111.0	5.0	none	5.5	65.5	none	66.5	63.0	none	64.0
4	102.0	none	106.0	5.0	none	5.5	67.0	none	68.7	64.0	none	64.7
6	105.0	109.0	112.0	4.5	4.5	4.5	65.5	65.3	67.6	6.8	61.5	61.2
8	95.0	100.0	112.0	4.5	4.5	6.0	65.0	65.0	67.0	60.4	62.5	60.50
				Stored at 50° F.								
2	107.0	none	110.0	5.5	none	5.5	68.0	none	70.5	64.0	none	66.5
4	104.0	none	108.0	5.2	none	5.5	70.7	none	69.0	64.7	none	66.8
6	99.5	108.0	109.0	5.0	5.5	5.0	66.5	67.5	66.3	60.8	64.5	63.0
8	99.0	107.0	111.0	4.5	5.0	5.0	65.0	66.2	68.0	60.0	61.9	62.5
				Stored at 70° F.								
2	100.0	none	115.0	5.0	none	5.0	64.0	none	68.5	63.0	none	65.5
4	89.0	none	110.0	3.5	none	5.5	62.0	none	66.0	60.1	none	65.3
6	82.0	83.0	112.0	3.5	2.5	6.0	60.0	63.0	65.6	56.4	55.4	60.4
8	79.0	80.0	111.0	2.5	3.0	5.5	60.0	59.0	64.5	60.0	54.0	60.0

TABLE IX (cont.)

Wks. in storage	Fruit volume %++			Peel thickness (mm.)			Axial diameter (mm.)			Equatorial diam. (mm.)		
Before storage	112.0			5.3			72.0			65.0		
	M*	Wr+	P#	M*	Wr+	P#	M*	Wr+	P#	M*	Wr+	P#
Stored at 84° F. (room)												
2	97.5	none	109.0	3.5	none	5.5	66.5	none	68.5	60.5	none	64.0
4	81.0	none	109.0	2.1	none	5.5	62.0	none	68.5	58.5	none	65.0
6	69.0	82.0	111.0	2.5	2.75	5.0	56.5	58.0	64.0	52.0	56.6	62.4
8	74.0	80.0	101.0	1.5	1.70	5.0	59.0	56.8	65.0	56.0	54.5	62.0

**Values are the average of 10 fruits
++Basis of 100 gms. original weight
*Fruit unwrapped and held in mesh bags
+Freuit paper-wrapped and held in mesh bags
#Fruit held in pliofilm bags

TABLE X

EFFECT OF TEMPERATURE AND KIND OF CONTAINER ON PERCENT JUICE OF VALENCIA ORANGE

(Percent juice per 100 gms. of original weight)
Before storage 50.0

Wks. in storage	40° F.			50° F.			70° F.			84° F. (room)		
	M*	Wr+	P#	M*	Wr+	P#	M*	Wr+	P#	M*	Wr+	P#
2	48.0	none	51.0	44.5	none	49.0	40.5	none	49.0	44.0	none	47.5
4	47.0	none	46.0	36.0	none	48.5	41.0	none	43.5	43.0	none	46.0
6	43.0	43.5	44.0	43.5	43.5	44.5	40.0	42.0	44.0	35.5	40.5	42.5
8	44.5	42.5	43.0	40.0	43.0	43.5	37.5	37.0	44.0	37.0	37.5	42.0

*Fruits unwrapped and held in mesh bags
+Fruits paper-wrapped and held in mesh bags
#Fruits held in pliofilm bags

Chemical Changes

The effect of temperature was readily seen in retarding or accelerating the changes in chemical constituents. Since only the degree of change in the components of fruit during storage is dependent on temperature, the following statements can be made for these changes.

Percent acid (basis of 100 cc. juice) showed an increase at the beginning of the storage period, followed by a decrease by the end of this period; in some cases it even reached levels below the initial acidity before storage (see Table XI). pH value remained about constant throughout the period; the difference between the maximum of 4 and the minimum of 3.8 did not exceed .2. This is because orange juice can undergo large changes in free acidity with relatively negligible changes in pH value, owing to the large buffer capacity of the juice.

Fruit held in pliofilm contained less acid percent than that in mesh bags. Percent soluble solid maintained the same direction as did percent acid. It showed an increase during the first part of the storage period, followed by a decrease in the latter part of this period, and reaching levels below the initial in some cases (see Table XII).

This decrease following an increase in both acid and soluble solid percents can be explained by the loss in these constituents through respiration. This loss far exceeded the artificial increase caused by the concentration of these

TABLE XI

CHANGES IN PERCENT ACID OF VALENCIA ORANGE

Wks. in storage	Percent acid (citric per 100 cc. juice) Before storage .84		
	M*	Wr+	P#
		Stored at 40°	
2	0.91	none	1.02
4	0.94	none	1.02
6	0.81	0.86	0.86
8	0.84	0.90	0.79
		Stored at 50°	
2	1.16	none	0.91
4	1.07	none	1.01
6	0.86	0.86	0.86
8	0.99	0.99	0.84
		Stored at 70°	
2	1.10	none	0.89
4	0.99	none	0.96
6	0.86	0.85	0.83
8	0.82	0.87	0.82
		Stored at 84° (room)	
2	0.86	none	0.85
4	0.92	none	0.77
6	0.80	0.80	0.85
8	0.78	0.79	0.75

*Fruit unwrapped and held in mesh bags.
+Fruit paper-wrapped and held in mesh bags
#Fruit held in pliofilm bags

TABLE XII

CHANGES IN PERCENT SOLUBLE SOLID AND SOLID/ACID RATIO OF VALENCIA ORANGE

Wks. in storage	Percent soluble solid++			Solid/acid ratio		
Before storage		11.4			13.6	
	M*	Wr+	P#	M*	Wr+	P#
Stored at 40° F.						
2	11.30	none	11.70	12.40	none	11.20
4	11.30	none	11.40	12.00	none	12.70
6	9.40	11.69	11.69	11.60	13.60	13.60
8	9.00	12.19	11.38	10.70	13.60	14.40
Stored at 50° F.						
2	12.00	none	11.50	10.40	none	12.70
4	10.70	none	10.80	11.40	none	12.10
6	9.13	11.38	12.00	10.60	13.30	14.00
8	9.50	11.94	12.10	9.60	12.00	14.50
Stored at 70° F.						
2	13.60	none	11.40	12.40	--	12.90
4	12.10	none	11.12	12.20	--	13.10
6	10.07	11.38	11.25	11.80	13.40	13.50
8	10.20	12.31	11.38	12.40	14.20	13.90

TABLE XII (cont.)

Wks. in storage	Percent soluble solid++			Solid/acid ratio		
Before storage	11.4			13.6		
	M*	Wr+	P#	M*	Wr+	P#
	Stored at 84° F. (room)					
2	13.20	none	12.00	15.40	none	14.10
4	12.63	none	12.25	15.60	none	15.90
6	12.63	12.60	13.29	15.70	15.80	15.70
8	11.88	12.63	13.29	15.20	16.00	17.80

++Basis of 100 cc. juice
*Fruits unwrapped and held in mesh bags
+Fruits paper-wrapped and held in mesh bags
#Fruits held in pliofilm bags

materials in the juice, and thus slowed the decrease by the end of the storage period.

Fruit held in pliofilm bags always showed less percent acid and soluble solid than that held in mesh bags. This is due to the dilution of these constituents in the film bags, which efficiently retained moisture.

Should percent soluble solid and percent acid be calculated on the basis of 100 gms. of original weight (see Table XIII), a decrease was detected. The higher the temperature, the more loss in soluble solid occurred; the least decrease was in fruit held in pliofilm bags. The decrease in soluble solid and acid is definitely due to the catabolic activities and the oxidation of these constituents. However, there was not much difference in the rate of decrease between the lower and higher temperatures.

Ratio solid/acid maintained a different pattern in the various bags. While it remained about constant or decreased slightly in fruit in mesh bags with prolonged storage (with the exception of room temperature), it continuously increased in fruit in pliofilm bags (see Table XII), along with the development of an acid taste in fruit in mesh bags and a flat taste in pliofilm bags. This may be attributed to the more rapid respiration of acids than solids in the pliofilm container, which may be related to the lower concentration of oxygen. This suggests the preferential use of acid in respiration at low oxygen tension. The reason that fruit in mesh bags at 84° F. showed an increase rather than a decrease

TABLE XIII

PROGRESSIVE CHANGES IN PERCENT SOLUBLE SOLID OF VALENCIA ORANGE HELD IN MESH BAGS

Wks. in storage	Percent soluble solid (Basis of 100 gms. original weight) Before storage 5.70	
	40°	70°
2	5.40	5.30
4	5.30	4.55
6	4.05	4.00
8	4.00	3.82

is probably due to the rapid loss in acidity at this high temperature.

Vitamin C percent on the basis of 100 cc. juice did not show any substantial change, probably due to the same reason mentioned in connection with grapefruit. On the basis of 100 grams, however, vitamin C percent has decreased; this action was slowed down at lower temperatures and by the use of pliofilm bags.

Table XIV summarizes vitamin C percent of fruit as affected by length of storage period, temperature, and kind of container. The variations among individual samples hindered any substantial difference in vitamin C content between fruit held in mesh bags and that tissue wrapped. There was also

TABLE XIV

PROGRESSIVE CHANGES IN VITAMIN C PERCENT OF VALENCIA ORANGE

Wks. in storage	Percent vitamin C (ascorbic acid) (Basis of 100 gms. original weight) Before storage 25.4			
	40°		70°	
	M*	P#	M*	P#
2	24.20	26.90	22.40	24.20
4	23.70	24.00	20.40	20.60
6	20.00	22.90	20.00	22.00
8	20.60	23.00	19.00	21.00

*Fruit unwrapped and held in mesh bags
#Fruit held in pliofilm bags

no difference in vitamin C content between fruit held at 40° and that held at 50° F.

Miscellaneous Observations

Perhaps of great importance is the effect of storage in retaining the original taste and appearance of the Valencia orange during the entire period. Changes in taste and flavor were more detectable than those in composition. At lower temperature the fruit retained its fresh taste without any kind of deterioration, all the way through the storage period. This was true regardless of kind of container. At higher temperatures there were varying degrees of taste change, depending on kind of container used. While fruit held in mesh bags and that tissue-wrapped developed off-flavor during prolonged storage, fruit held in pliofilm developed a sweet and flat taste.

Color of rind was affected in direct relation to loss in moisture. The more moisture loss, the more the fruit lost its brightness and developed a duller shade.

As was the case with Marsh seedless grapefruit, pliofilm preserved the original quality appearance for a longer time, especially at lower temperatures. It showed marked efficiency in preventing dehydration and the resulting off-shape and dull appearance. It is worthwhile to note that the Valencia orange has proved superior to other citrus varieties included in this test in retaining its good appearance after a long time in storage.

Figure V shows Valencia oranges after 11 months in storage at 50° F. in pliofilm bags. The good appearance, however, might not correspond with changes in the constituents, taste, or eating quality. In other words, the fruit might keep its original good shape and fresh outside appearance, and yet become unpalatable due to progressive changes in constituents.

Pitting: No pitting was detected in Valencia orange at any temperature used in this test, which is evidence that this orange is not as susceptible to severe pitting as are

Figure V Valencia orange after eleven months in storage at 50° F. in pliofilm bags.

other varieties of citrus.

Decay: Blue and green molds were the only decays encountered in the storage of Valencia orange. Their severity corresponded to high temperature and humidity, as indicated by the greater infestation of fruit held at 70° F. and especially of fruit held in pliofilm bags.

Washington Naval Orange

Experimental work with the Washington Naval orange was started in December, 1949 when they were bagged and held in the different storage rooms. Analyses were made on the fruit at 3-week intervals throughout the entire storage period of 12 weeks.

Physical Changes

Loss in weight: Table XV contains data on loss in weight of Naval oranges in storage. Generally speaking, the fruit lost most weight at the higher temperatures, the loss decreasing with descending temperatures and being least at 40° F. Much of the loss was due to loss in moisture but some was lost by respiration. The fruit lost most of its weight during the first 3 weeks, with a gradual decrease during successive weeks.

It is readily seen from the table that fruit stored at 40° lost 8.55 percent from its weight after 3 weeks, while that stored at 70° lost about once and a half this value, providing both were held in mesh bags. Naval oranges responded to loss in weight more than did the Valencia, due to the higher rate of moisture loss from its thicker peel.

Fruit held in mesh bags lost about 4 times as much as that in pliofilm bags. Wrapping tissue had an appreciable effect in retarding weight loss. Figure 6 and Table XV bring out clearly the effect of different containers and temperatures on the amount of weight loss.

As with loss in weight, most of the loss in volume occurred within the first 3 weeks in storage and then gradually decreased until the end of the period. Thickness of peel and fruit diameters also showed a decrease, there being a direct relation between the rate of decrease in these measurements and the degree of loss of moisture (see Table XVI).

Percent of juice per 100 grams of original weight also showed decreasing values, but at a less pronounced rate. Table XVII shows the retarding effect of low temperature and pliofilm bags in the alteration of juice percent. Percent juice on the basis of fruit volume at the time of analysis showed an increase during storage, due to volume being lost at a more rapid rate than juice.

Chemical Changes

Data concerning changes in acid percent of juice are summarized in Table XVIII. There was a progressive increase in percent acid (mgs. per 100 cc. of juice) with prolonged

TABLE XV

LOSS IN WEIGHT OF WASHINGTON NAVAL ORANGE

Temperature	Wks. in storage	Weight before storage (gms.)** M*	Wr+	P#	Percent loss in weight M*	Wr+	P#
40° F.	3	199	226	215	8.55	7.10	1.86
	6	217	224	220	7.38	7.70	1.36
	9	216	213	221	10.60	9.90	1.81
	12	221	220	213	14.00	12.30	2.02
50° F.	3	217	224	212	6.92	6.70	1.88
	6	216	228	226	7.42	8.30	2.21
	9	222	245	208	11.30	8.60	1.92
	12	232	226	211	12.50	9.30	2.37
70° F.	3	229	238	225	13.90	11.80	3.10
	6	222	223	210	21.10	19.70	5.25
	9	222	228	218	26.50	25.40	8.80
	12	217	214	211	33.60	33.10	9.00
77° F. (room)	3	226	219	222	17.30	21.30	4.95
	6	229	208	225	33.60	31.20	9.80
	9	233	229	217	40.00	48.60	8.80
	12	208	235	213	50.00	46.80	15.00

**Average of 5 fruits
*Fruit unwrapped and held in mesh bags
+Fruit paper-wrapped and held in mesh bags
#Fruit held in pliofilm bags

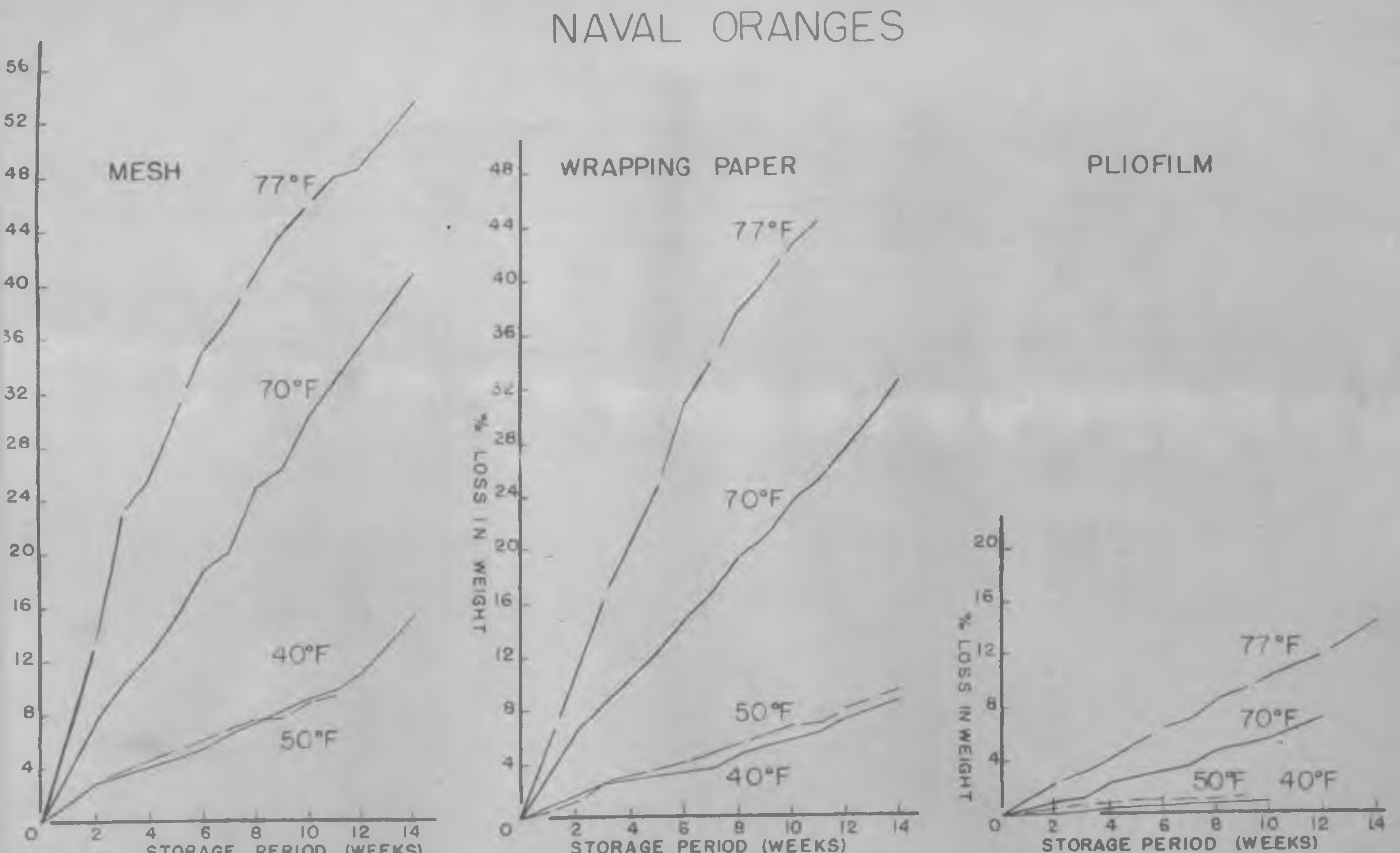

FIG VI PERCENT LOSS IN WEIGHT IN NAVAL ORANGES STORED AT VARIOUS TEMPERATURES IN DIFFERENT CONTAINERS AS AFFECTED BY THE LENGTH OF STORAGE PERIOD.

TABLE XVI

SOME PHYSICAL CHANGES IN WASHINGTON NAVAL ORANGE AS AFFECTED BY KIND OF CONTAINER AND LENGTH OF STORAGE PERIOD

	Fruit volume %++			Peel thickness (mm.)			Axial diameter (mm.)			Equatorial diam. (mm.)		
Before storage	118.0			6.5			83.0			72.0		
Wks. in storage	M*	Wr+	P#	M*	Wr+	P#	M*	Wr+	P#	M*	Wr+	P#
					Stored at 40° F.							
3	105.0	107.0	117.0	6.0	6.5	7.0	75.4	76.4	80.4	71.6	72.0	73.4
6	103.0	102.0	116.0	5.0	6.5	6.5	74.0	75.8	77.0	69.2	72.2	73.2
9	104.0	104.0	115.0	6.0	6.25	6.5	74.0	75.0	76.4	71.0	71.8	73.2
12	97.0	101.0	116.0	5.0	6.0	6.25	74.0	75.2	76.0	69.2	69.2	72.2
					Stored at 50° F.							
3	110.0	109.0	114.0	6.5	6.75	6.5	76.4	77.4	76.4	72.2	74.0	72.6
6	104.0	106.0	107.0	6.5	6.25	5.75	76.4	77.2	76.6	71.8	72.0	72.4
9	102.0	104.0	110.0	6.0	5.5	6.25	74.4	77.8	77.0	71.2	73.6	72.0
12	100.0	98.0	111.0	5.5	6.0	5.3	73.0	74.0	75.6	70.5	73.0	73.0
					Stored at 70° F.							
3	99.0	108.0	117.0	5.75	5.0	6.5	76.2	69.4	78.2	69.2	72.5	74.0
6	82.0	88.0	107.0	4.5	5.0	6.75	71.6	72.0	76.4	67.0	68.2	71.8
9	85.0	80.0	108.0	3.5	4.25	6.0	68.8	72.0	76.0	65.8	67.8	72.0
12	70.0	82.0	107.0	3.5	4.0	5.0	67.0	68.0	75.2	62.0	65.2	70.6

TABLE XVI (cont.)

	Fruit volume %++			Peel thickness (mm.)			Axial diameter (mm.)			Equatorial diam. (mm.)		
Before storage	118.0			6.5			83.0			72.0		
Wks. in storage	M*	Wr+	P#	M*	Wr+	P#	M*	Wr+	P#	M*	Wr+	P#
				Stored at 77° F. (room)								
3	98.0	87.0	106.0	4.5	3.5	6.0	73.8	71.2	79.5	67.4	65.6	73.0
6	65.5	70.5	105.0	2.25	3.0	6.0	66.8	67.0	75.0	63.0	63.0	71.0
9	65.0	66.5	107.0	2.0	2.5	5.5	68.0	65.8	74.0	63.0	69.6	71.5
12	59.0	63.0	107.0	2.0	2.5	5.0	61.2	66.0	73.5	58.2	61.4	70.5

**Values are average of 5 fruits
++Basis of 100 gms. original weight
*Fruit unwrapped and held in mesh bags
+Fruit paper-wrapped and held in mesh bags
#Fruit held in pliofilm bags

TABLE XVII

EFFECT OF TEMPERATURE AND KIND OF CONTAINER ON PERCENT JUICE OF WASHINGTON NAVAL ORANGE

(Percent juice per 100 gms. of original weight)
Before storage 40.0

Wks. in storage	40° F.			50° F.			70° F.			77° F. (room)		
	M*	Wr+	P#	M*	Wr+	P#	M*	Wr+	P#	M*	Wr+	P#
3	39.0	36.0	37.0	35.0	40.5	40.0	33.0	37.0	36.0	34.0	36.0	38.0
6	39.0	39.0	36.0	34.0	37.0	37.0	31.5	35.0	36.0	30.0	38.0	32.0
9	36.0	32.0	35.0	33.0	34.0	34.0	30.0	33.0	34.5	25.8	30.0	34.0
12	38.0	34.0	36.6	35.6	35.0	35.6	35.0	35.0	34.0	22.0	26.0	30.5

*Fruit unwrapped and held in mesh bags
+Fruit paper-wrapped and held in mesh bags
#Fruit held in pliofilm bags

TABLE XVIII

CHANGES IN PERCENT ACID OF WASHINGTON NAVAL ORANGE

Wks. in storage	Percent acid (citric per 100 cc. juice) Before storage 0.70		
	M*	Wr+	P#
		Stored at 40° F.	
3	0.75	0.73	0.70
6	0.82	0.84	0.83
9	0.88	0.85	0.80
12	0.80	0.80	0.77
		Stored at 50° F.	
3	0.65	0.70	0.62
6	0.82	0.76	0.76
9	0.82	0.77	0.72
12	0.83	0.80	0.68
		Stored at 70° F.	
3	0.63	0.67	0.53
6	0.77	0.76	0.76
9	0.85	0.82	0.65
12	0.84	0.88	0.74
		Stored at 77° F. (room)	
3	0.73	0.75	0.66
6	0.73	0.85	0.65
9	0.83	0.79	0.72
12	0.86	0.91	0.67

*Fruit unwrapped and held in mesh bags
+Fruit paper wrapped and held in mesh bags
#Fruit held in pliofilm bags.

storage, the increase being more from the lower to the higher temperatures. Fruit held in pliofilm bags had less percent acid than that held in other bags.

pH value remained about constant during storage, with a difference of only 0.4 between the maximum of 4 and the minimum of 3.6.

Percent soluble solid showed an increase which was continuous at higher temperatures but decreased by the end of the storage period at lower temperatures (see Table XIX). Fruit held in pliofilm bags showed less acid and soluble solid percents due to the diluted constituents of the fruit.

If percent soluble solid and acid were calculated on the basis of 100 gms. of original weight, they showed a decrease during storage. The higher the temperature, the more loss in soluble solid took place; the least loss occurred in fruit in pliofilm bags, since those bags slowed down the catabolic activities.

Ratio solid/acid showed an increase during the first three weeks in storage at lower temperatures, followed by a slight decrease in the following weeks, probably due to the preferential use of acid in respiration during the first three weeks and the use of both acid and other soluble solid in respiration during successive weeks. At room temperature there was an increase in the ratio, then it remained about constant with prolonged storage. However, fruit in pliofilm bags showed higher ratios than that in other bags, fortified

TABLE XIX

CHANGES IN PERCENT SOLUBLE SOLID AND SOLID/ACID RATIO
OF WASHINGTON NAVAL ORANGE

Wks. in storage	Percent soluble solid++			Solid/acid ratio		
Before storage		11.38			16.25	
	M*	Wr+	P#	M*	Wr+	P#
		Stored at 40° F.				
3	12.00	12.31	12.12	15.90	16.90	17.35
6	11.38	12.00	11.31	13.90	14.30	13.65
9	11.10	12.69	12.00	12.36	14.00	14.90
12	10.30	11.20	11.12	12.80	14.00	14.50
		Stored at 50° F.				
3	12.00	12.63	11.50	18.30	18.10	18.60
6	12.44	12.63	11.38	15.20	16.65	15.00
9	12.75	12.00	11.00	15.60	15.50	15.30
12	12.75	11.88	11.31	15.40	14.70	16.70
		Stored at 70° F.				
3	11.56	13.29	12.00	18.40	19.70	22.60
6	13.29	13.36	(12.15)	17.25	17.60	18.85
9	13.29	14.00	12.31	15.50	17.00	18.85
12	14.00	14.63	12.12	16.70	16.70	16.40

TABLE XIX (cont.)

Wks. in storage	Percent soluble solid++			Solid/acid ratio		
Before storage		11.38			16.25	
	M*	Wr+	P#	M*	Wr+	P#
		Stored at 77° F. (room)				
3	12.63	12.63	12.31	17.30	16.75	18.50
6	14.50	13.29	11.38	19.90	16.50	17.35
9	14.00	13.29	11.80	17.00	16.80	16.40
12	15.94	15.63	12.20	18.50	16.90	18.20

++Basis of 100 cc. juice
*Fruit unwrapped and held in mesh bags
+Fruit paper-wrapped and held in mesh bags
#Fruit held in pliofilm bags

by the development of flat taste during the course of the experiment.

Vitamin C percent (mgs. ascorbic per 100 gms. original weight) showed a very marked decrease at higher temperatures after 12 weeks in storage. The effect of temperature on vitamin C loss is quite obvious by looking at Table XXI, even with fruit held in pliofilm bags. While the vitamin C percent was 21.6 before storage, it became 9.9 when held in mesh bags and 13.7 in pliofilm bags after 12 weeks. However, fruit stored at 40° F. did not show any substantial loss, even with prolonged storage.

Miscellaneous Observations

Changes in taste and flavor of juice were more pronounced than changes in chemical constituents. The taste of Naval oranges was seriously affected, even after a short time in storage. Taste deterioration was manifested by the development of stale, insipid, disagreeable flavors, especially by the end of the 12-week period. It seems this fruit is very sensitive to the unbalance of the respiratory ratio caused by the accumulation of CO_2 in the film. However, a flat taste always accompanied fruit stored at high temperatures or held in pliofilm bags.

The color of rind had a direct correlation with rate of loss in moisture. The more dehydration in the fruit, the greater development of a dull shade took place.

TABLE XX

PROGRESSIVE CHANGES IN PERCENT SOLUBLE SOLID
OF WASHINGTON NAVAL ORANGE STORED IN MESH BAGS

Wks. in storage	Percent soluble solid (Basis of 100 gms. original weight) Before storage 4.35	
	40°	77°
3	4.10	4.00
6	4.40	4.20
9	4.00	3.62
12	3.90	3.50

TABLE XXI

PERCENT VITAMIN C OF NAVAL ORANGE
BEFORE AND AFTER 12 WEEKS IN STORAGE

Wks. in storage 12	Percent vitamin C (ascorbic acid) per 100 gms. of original weight Before storage 21.6	
Temperature	M*	P#
40° F.	18.90	20.00
77° F. (room)	9.90	12.70

*Fruit unwrapped and held in mesh bags
#Fruit held in pliofilm bags

Figure VII shows Naval oranges stored at 50° F. in the 3 kinds of containers. The effect of pliofilm on the external appearance of this fruit is quite obvious.

Pitting: In contrast to the Valencia orange which did not develop pitting at any temperature, the Naval orange developed this defect in storage at 40° but only at the end of 12 weeks, at which time a few sunken spots appeared.

Decay: Although Naval oranges were subjected to the standard treatment with borax solution, packed as Sunkist grade, this did not hinder the development of rots even at the lowest temperatures. Blue and green molds were a serious trouble, especially at 70° with high humidity. Pliofilm favored the severity of decay. Naval end rot was also observed at higher temperatures; and by the end of the storage period, fruit stored at 40° F. in pliofilm bags developed sour rot.

Algerian Tangerine

Work with the Algerian tangerine was started in December, 1949 when fruit was put in the storage room. It was held for 12 weeks, and analyses were made at 3-week intervals.

Physical Changes

Loss in weight: Table 22 and Figure VIII show the effect of different temperatures and kinds of containers on percent loss in weight.

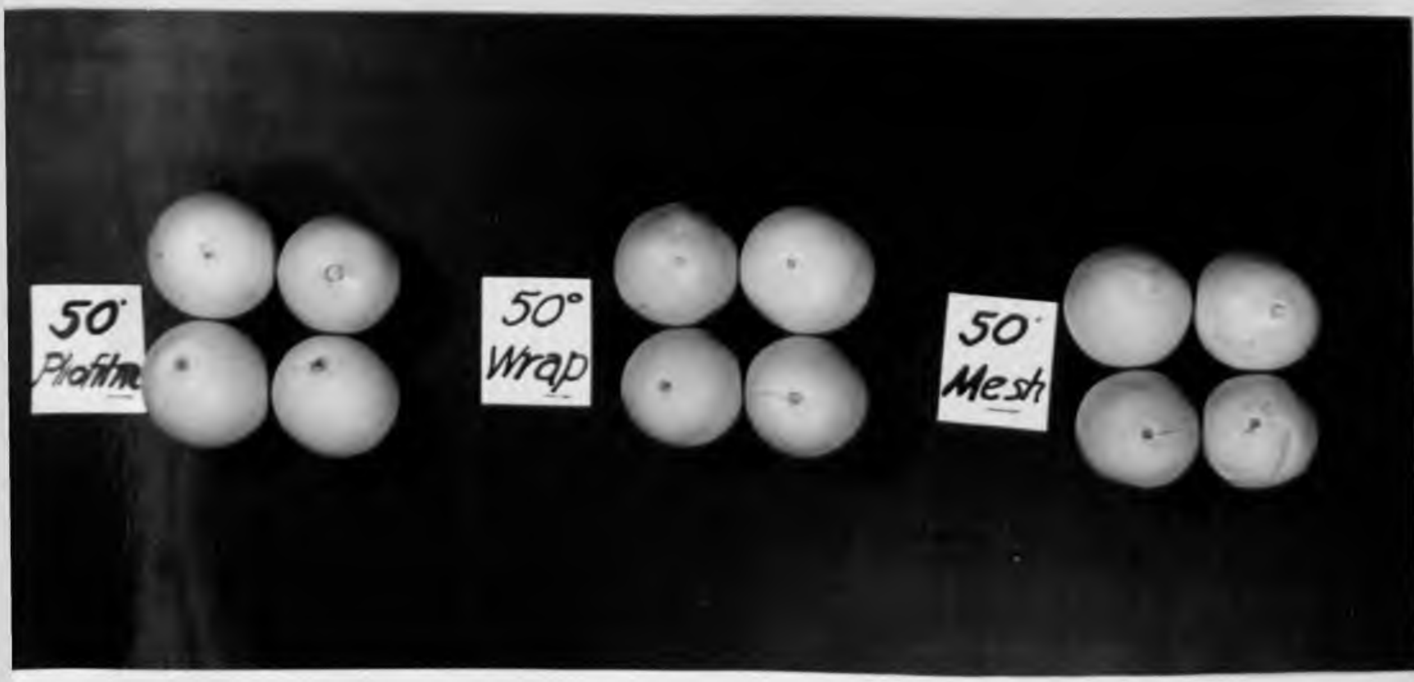

Figure VII Naval orange after four months in storage at 50° F. in different containers.

TABLE XXII

LOSS IN WEIGHT OF ALGERIAN TANGERINE

Temperature	Wks. in storage	Weight before storage (gms.)**			Percent loss in weight		
		M*	Wr+	P#	M*	Wr+	P#
40° F.	3	96	85	84	11.50	14.20	0.0
	6	96	92	88	15.60	14.40	3.41
	9	82	84	90	9.75	20.20	2.22
	12	95	88	90			
50° F.	3	101	102	97	9.90	12.70	3.12
	6	76	87	92	17.10	18.40	2.28
	9	58	81	90	20.70	21.00	3.90
	12	84	90	89	22.60	20.00	1.67
70° F.	3	101	104	83	22.80	21.10	6.04
	6	117	95	88	22.30	33.70	7.95
	9	84	98	97	26.50	41.80	9.80
	12	90	95	97	53.30	50.50	6.20
77° F. (room)	3	78	101	88	35.90	31.60	10.20
	6	88	80	85	41.00	43.80	15.30
	9	84	73	99	29.80	59.00	21.20
	12	86	97	84	66.80	17.50	4.75

**Average of 5 fruits
*Fruit unwrapped and held in mesh bags
+Fruit paper-wrapped and held in mesh bags
#Fruit held in pliofilm bags

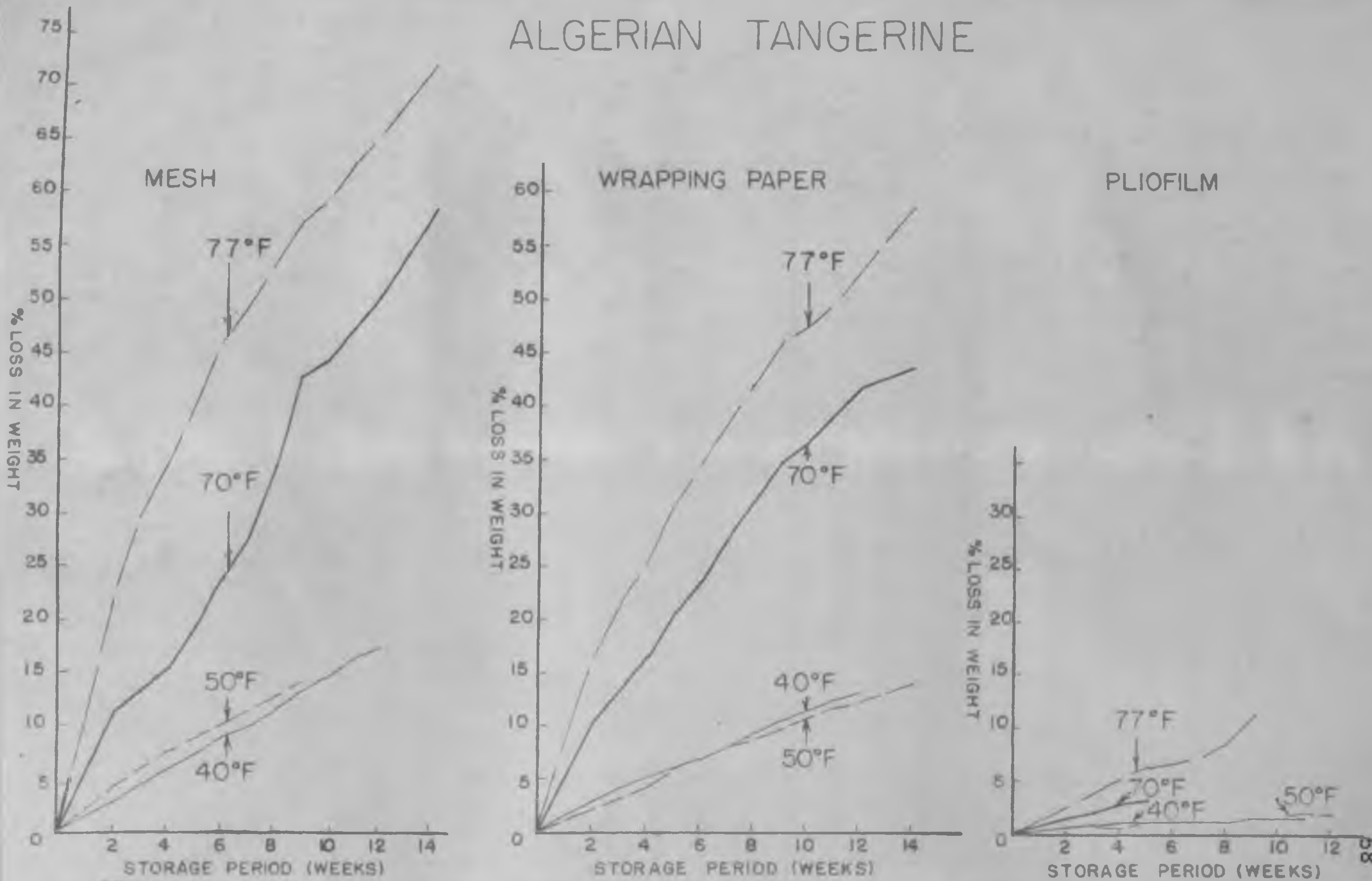

FIG VIII PERCENT LOSS IN WEIGHT IN ALGERIAN TANGERINE STORED AT VARIOUS TEMPERATURES IN DIFFERENT CONTAINERS AS AFFECTED BY THE LENGTH OF STORAGE PERIOD.

Comparing the temperature effect, it may be seen that as a general rule fruit in any kind of container lost the most weight at 77° and the least ar 40° F., with intermediate losses at other temperatures. Fruit held at 70° in ordinary mesh bags lost about twice as much as that held at 40° after 3 weeks in storage. In general, fruit lost most of its weight during the first 3 weeks.

The pliofilm bags had a definite effect in decreasing percent loss in weight. They succeeded in decreasing moisture loss to a minimum, so fruit lost only about one-fourth as much as fruit in mesh bags. Tissue wrap was superior to ordinary mesh bags in this respect also.

There was a direct relation between loss in moisture and the amount of decrease in the measurements of the tangerine. Most volume loss occurred within the first 3 weeks, with a much slower rate of decrease during successive weeks. The higher the temperature, the more loss in volume.

Pliofilm gave the most satisfactory results in holding the volume decrease to a minimum. Tissue wrap proved much inferior to pliofilm but slightly superior to mesh bags in this respect. Table XXIII summarizes the changes in volume, thickness of peel, and diameters. Thickness of peel and diameters showed a slight decrease during storage, depending on temperature and kind of bag.

TABLE XXIII

SOME PHYSICAL CHANGES IN ALGERIAN TANGERINE AS AFFECTED BY KIND OF CONTAINER AND LENGTH OF STORAGE PERIOD**

	Fruit volume %++			Peel thickness (mm.)			Axial diameter (mm.)			Equatorial diam. (mm.)		
Before storage	120.0			2.75			40.0			55.0		
Wks. in storage	M*	Wr+	P#	M*	Wr+	N#	M*	Wr+	P#	M*	Wr+	P#
					Stored at 40° F.							
3	91.5	96.5	115.0	2.5	3.0	2.75	51.2	49.6	51.6	51.6	52.0	50.4
6	93.5	95.5	110.0	2.25	2.75	2.5	50.2	52.5	54.6	52.6	51.8	54.4
9	90.0	92.0	104.0	2.5	2.5	2.75	50.4	52.0	52.6	52.0	50.8	52.0
12	91.0	85.0	109.0	2.5	2.5	2.75	50.2	51.0	52.6	52.6	52.8	50.0
					Stored at 50° F.							
3	95.0	102.0	109.0	2.75	2.75	2.75	51.8	50.6	55.0	55.0	55.2	55.6
6	92.0	101.0	98.0	2.5	2.75	2.7	45.0	50.2	54.0	55.4	50.4	54.5
9	93.0	101.0	107.0	2.5	2.75	2.75	42.2	47.0	50.0	51.2	51.2	54.0
12	90.0	94.5	101.0	2.75	2.50	2.75	47.5	50.3	50.3	54.0	54.0	53.0
					Stored at 70° F.							
3	90.0	92.0	110.0	2.5	2.5	2.75	45.8	50.2	50.0	53.2	53.0	53.6
6	80.0	78.0	100.0	2.25	2.0	2.75	50.6	46.2	50.4	52.8	49.0	55.0
9	68.0	67.5	104.0	1.0	1.5	2.5	41.4	46.0	52.8	46.2	48.6	54.4
12	69.0	65.5	97.0	1.5	1.25	2.5	40.2	44.6	50.0	46.0	47.0	54.0

TABLE XXIII (cont.)

	Fruit volume %++			Peel thickness (mm.)			Axial diameter (mm.)			Equatorial diam. (mm.)		
Before storage	120.0			2.75			40.0			55.0		
Wks. in storage	M*	Wr+	P#	M*	Wr+	P#	M*	Wr+	P#	M*	Wr+	P#
				Stored at 77° F. (room)								
3	81.5	74.0	109.0	1.5	2.0	2.5	42.6	45.8	49.2	46.8	51.0	53.2
6	75.0	76.0	94.0	1.0	1.0	2.5	42.2	40.8	47.6	47.4	45.6	51.0
9	83.0	79.5	102.0	1.0	1.0	2.0	42.2	39.2	47.2	46.4	41.8	53.8
12	74.5	75.0	100.0	0.5	0.75	2.0	41.6	40.0	42.0	43.0	41.6	52.0

**Values are average of 5 fruits
++Basis of 100 gms. original weight
*Fruit unwrapped and held in mesh bags
+Fruit paper-wrapped and held in mesh bags
#Fruit held in pliofilm bags

Percent juice on the basis of 100 grams of original weight decreased in storage, being particularly distinct in fruits stored at higher temperatures. It is of interest to note that the juice constituents in the tangerine were seriously affected by storage. Looking at Table XXIV it is noted that while percent juice was 45 before storage, it sustained levels as low as 5.8 by the end of the storage period when held at 77° F. in mesh bags.

Meanwhile the fruit did not show a corresponding degree of decrease in diameters. This is due to the fact that the tangerine has a very high rate of transpiration through the pores in the peel, which rapidly caused the dehydration of moisture and consequent drying out of juice. During the experimental work it was observed that the fruit looked hollow from the inside. In fact, scarcely enough juice for chemical analysis could be extracted from the 5-fruit samples. However, factors which enhanced loss in moisture always favored loss in juice.

In expressing percent juice per fruit volume at the time of analysis, there was an increase during the first part of the storage period followed by a decrease in the following weeks. This is an indication that, while most moisture loss was from the peel and caused a decrease in volume at the beginning, by prolonged storage the juice loss speeded up to a maximum far exceeding loss in volume and resulting in a decrease in percent of juice.

TABLE XXIV

EFFECT OF TEMPERATURE AND KIND OF CONTAINER ON PERCENT JUICE OF ALGERIAN TANGERINE

(Percent juice per 100 gms. of original weight)
Before storage 45.0

Wks. in storage	40° F.			50° F.			70° F.			77° F. (room)		
	M*	Wr+	P#	M*	Wr+	P#	M*	Wr+	P#	M*	Wr+	P#
3	37.5	37.5	45.0	40.0	38.5	44.0	36.0	38.0	42.0	30.0	38.0	39.0
6	35.5	37.0	41.0	37.0	35.0	33.0	26.0	35.0	38.0	29.0	32.5	37.0
9	35.0	36.0	40.0	36.0	32.0	31.0	25.0	26.5	36.5	24.0	13.5	36.0
12	26.0	25.5	30.0	29.0	31.0	32.0	20.0	23.0	32.5	5.8	14.5	31.0

*Fruit unwrapped and held in mesh bags
+Fruit paper-wrapped and held in mesh bags
#Fruit held in pliofilm bags

Chemical Changes

Table XXV gives the figures for percent acid in Algerian tangerines at different temperatures and in various containers.

Percent acid showed a continuous increase, being correlated with loss in moisture. The more loss in water content of the fruit, the greater increase in percent acid. Percent soluble solid also showed this same reaction (see Table XXVI). This increase in percent acid and soluble solid is due to the concentration of juice constituents as a result of dehydration.

Should percent soluble solid and acid be calculated on the basis of 100 grams of original weight, they showed a decrease by time in storage due to the life activities of the fruit. Catabolic activities were materially slowed down at lower temperatures. It is readily seen from Table XXVII that the fruit lost about one-fifth of its solid constituents after 12 weeks in storage at 70° F. when held in mesh bags. Low temperature and pliofilm bags had an appreciable effect in retarding the rate of loss in the solid constituents.

pH value did not show any considerable change in storage, probably due to the stability of the hydrogen ion concentration and the large buffer capacity of the juice. The difference between the maximum and minimum values did not exceed .3 (maximum 3.6, minimum 3.3).

TABLE XXV

CHANGES IN PERCENT ACID OF ALGERIAN TANGERINE

Wks. in storage	Percent acid (citric per 100 cc. juice) Before storage .90		
	M*	Wr+	P#
	Stored at 40° F.		
3	0.88	0.93	0.98
6	0.96	0.97	0.97
9	0.96	0.91	0.95
12	0.99	0.95	0.85
	Stored at 50° F.		
3	0.95	0.89	0.84
6	0.95	0.89	0.87
9	0.95	1.00	0.91
12	1.21	0.86	0.71
	Stored at 70° F.		
3	1.08	0.91	1.06
6	1.09	1.15	1.23
9	1.59	1.40	1.15
12	1.76	1.45	1.01
	Stored at 77° F. (room)		
3	1.04	1.12	1.02
6	1.26	1.32	1.06
9	1.51	1.72	1.29
12	1.87	1.81	1.07

*Fruit unwrapped and held in mesh bags
+Fruit paper-wrapped and held in mesh bags
#Fruit held in pliofilm bags

TABLE XXVI

CHANGES IN PERCENT SOLUBLE SOLID AND SOLID/ACID RATIO OF ALGERIAN TANGERINE

Wks. in storage	Percent soluble solid++			Solid/acid ratio		
Before storage		12.0			13.3	
	M*	Wr+	P#	M*	Wr+	P#
			Stored at 40° F.			
3	12.56	13.29	12.06	14.30	14.30	12.30
6	13.00	12.69	12.63	13.50	13.00	13.30
9	13.14	13.93	12.00	13.70	15.30	13.65
12	13.50	13.64	12.63	13.60	14.30	14.20
			Stored at 50° F.			
3	13.21	12.94	12.63	13.90	14.55	15.05
6	11.31	13.21	12.69	(13.55)	14.90	14.60
9	12.56	14.31	12.88	13.20	14.30	14.15
12	14.31	12.94	12.12	14.80	15.10	17.00
			Stored at 70° F.			
3	13.29	14.06	13.36	(14.15)	15.00	12.06
6	13.79	15.25	13.29	12.65	13.25	12.60
9	17.10	17.10	13.57	10.80	12.20	13.00
12	19.45	20.25	14.75	11.00	14.00	14.60

TABLE XXVI (cont.)

Wks. in storage	Percent soluble solid++			Solid/acid ratio		
Before storage	12.0			13.3		
	M*	Wr+	P#	M*	Wr+	P#
	Stored at 77° F. (room)					
3	15.00	14.50	13.29	14.40	13.00	13.00
6	14.63	15.25	14.00	11.16	11.50	13.20
9	17.40	20.90	15.06	11.50	12.20	14.50
12	23.40	27.65	16.80	12.50	15.30	15.70

++Basis of 100 cc. juice
*Fruit unwrapped and held in mesh bags
+Fruit paper-wrapped and held in mesh bags
#Fruit held in pliofilm bags

TABLE XXVII

PROGRESSIVE CHANGES IN PERCENT SOLUBLE SOLID OF ALGERIAN TANGERINE HELD IN MESH BAGS

Wks. in storage	Percent soluble solid (Basis of 100 gms. original weight) Before storage 5.40	
	40° F.	70° F.
3	4.70	4.50
6	4.60	4.25
9	4.60	4.15
12	3.50	1.35

Ratio solid/acid showed an increase in storage, which remained about constant at lower temperatures but showed a slight decrease with prolonged storage. Fruit held in pliofilm bags at higher temperatures, however, showed a continuous increase in the ratio and had higher ratios than fruit held in other bags. This was fortified by the development of a relatively flat taste in fruit in the film, probably due to the more rapid respiration of acid than solid.

Percent vitamin C (mgs. per 100 gms. of original weight) showed a decrease. The higher the temperature, the greater loss in ascorbic acid took place.

Table XXVIII summarizes the changes in vitamin C percent in fruit held at 40° and 77° F. for 12 weeks. It also shows

TABLE XXVIII

PERCENT VITAMIN C OF ALGERIAN TANGERINE
BEFORE AND AFTER 12 WEEKS STORAGE

Temperature	Percent vitamin C (ascorbic acid) per 100 gms. of original weight Before storage 25	
	M*	P#
40° F.	13.70	17.30
77° F. (room)	5.60	15.00

*Fruit unwrapped and held in mesh bags
#Fruit held in pliofilm bags

the efficiency of pliofilm in retarding the loss in vitamin C. It may be noted from the table that fruit held at 77° in mesh bags contained about one-fifth as much vitamin C as before storage. When expressing vitamin C percent on the basis of 100 cc. of juice at the time of analysis, it showed an outstanding increase in fruit held at 77° in mesh bags. This is not due to ascorbic acid building up in the juice, but is a result of the concentration of the vitamin per unit volume due to dehydration. (See Appendix B.)

Miscellaneous Observations

Algerian tangerine is probably the only citrus variety experimented with here whose taste did not deteriorate with storage; most of the fruit was acceptable, as far as taste was concerned, during the entire storage period. The only exception was that stored at 77° which developed varying degrees of shrinkage, off-shape, blemishes, and rind breakdown which were in direct relation to temperature. Since low temperature and pliofilm were the factors controlling moisture loss, they can be given credit for retaining the good appearance of the fruit.

It is noteworthy that Algerian tangerines were harvested by the standard procedure of clipping them with 2 leaves attached, and fruit was stored in this condition. All leaves shriveled during the first week at all temperatures, but with much less shriveling at 40 and 50° F. Shriveling was followed by the drying out at higher temperatures, and leaves attained a leathery texture at the lower temperatures. Pliofilm bags did not prevent the dropping of leaves which accompanied shriveling. Leaves in the film lost their green color, turning leathery and purplish, and were soon infected by various contaminations. All these leaf changes occurred within the first 2 weeks in storage.

Pitting: This was almost entirely absent in the tangerine under the conditions employed in this experiment.

Decay: Decay was a serious trouble encountered with the tangerine in storage. In addition to blue and green molds, alternaria mold was more serious at higher temperatures and even at 50° F. Sour rot also showed up in the fruit held at 40° in pliofilm bags by the end of the period.

Eureka Lemon

Data on lemon storage were obtained from fruit put into storage in November, 1949. Analyses were made at 3-week intervals throughout the entire storage period which was terminated at the end of the 12th week.

Physical Changes

Loss in weight: The various samples stored at any temperature in any container lost weight. The mean loss, however, was not the same for the different storage conditions. At higher temperatures where no wrap was used, the loss in weight was about two times that at lower temperatures for the same period.

Table XXIX summarizes the data on percent loss in weight. It clearly shows that the greatest loss occurred within the first few weeks, with a continuing loss as the storage period advanced.

While wrapping paper had a slight effect in retarding loss in weight, pliofilm showed marked efficiency in this respect. Fruit held in mesh bags lost three to four times as much as fruit held in pliofilm bags. Figure VIII and Table XXIX plainly indicate the effect of pliofilm in preventing weight loss. They also show the response of loss in weight to high temperatures.

TABLE XXIX

LOSS IN WEIGHT OF EUREKA LEMONS

Temperature	Wks. in storage	Weight before storage (gms.)** M*	Wr+	P#	Percent loss in weight M*	Wr+	P#
40° F.	3	100	102	97	13.0	14.7	4.1
	6	98	102	109	16.3	20.6	3.7
	9	101	102	110	20.8	18.8	4.5
	12	105	96	100	17.1	24.0	6.0
50° F.	3	102	104	96	13.7	10.6	3.1
	6	104	106	99	14.4	16.0	4.0
	9	107	109	97	17.8	19.5	5.7
	12	115	109	97	20.9	20.2	6.2
70° F.	3	111	112	101	25.2	24.3	6.9
	6	110	125	100	29.1	30.4	10.0
	9	101	114	107	35.6	35.0	12.3
	12	109	100	101	39.5	27.0	16.8
77° F. (room)	3	108	104	95	26.8	28.9	12.6
	6	112	113	93	36.6	39.8	22.6
	9	109	118	96	43.1	46.6	26.1
	12	101	129	94	54.5	53.5	34.1

**Average of 5 fruits
*Fruit unwrapped and held in mesh bags
+Fruit paper-wrapped and held in mesh bags
#Fruit held in pliofilm bags

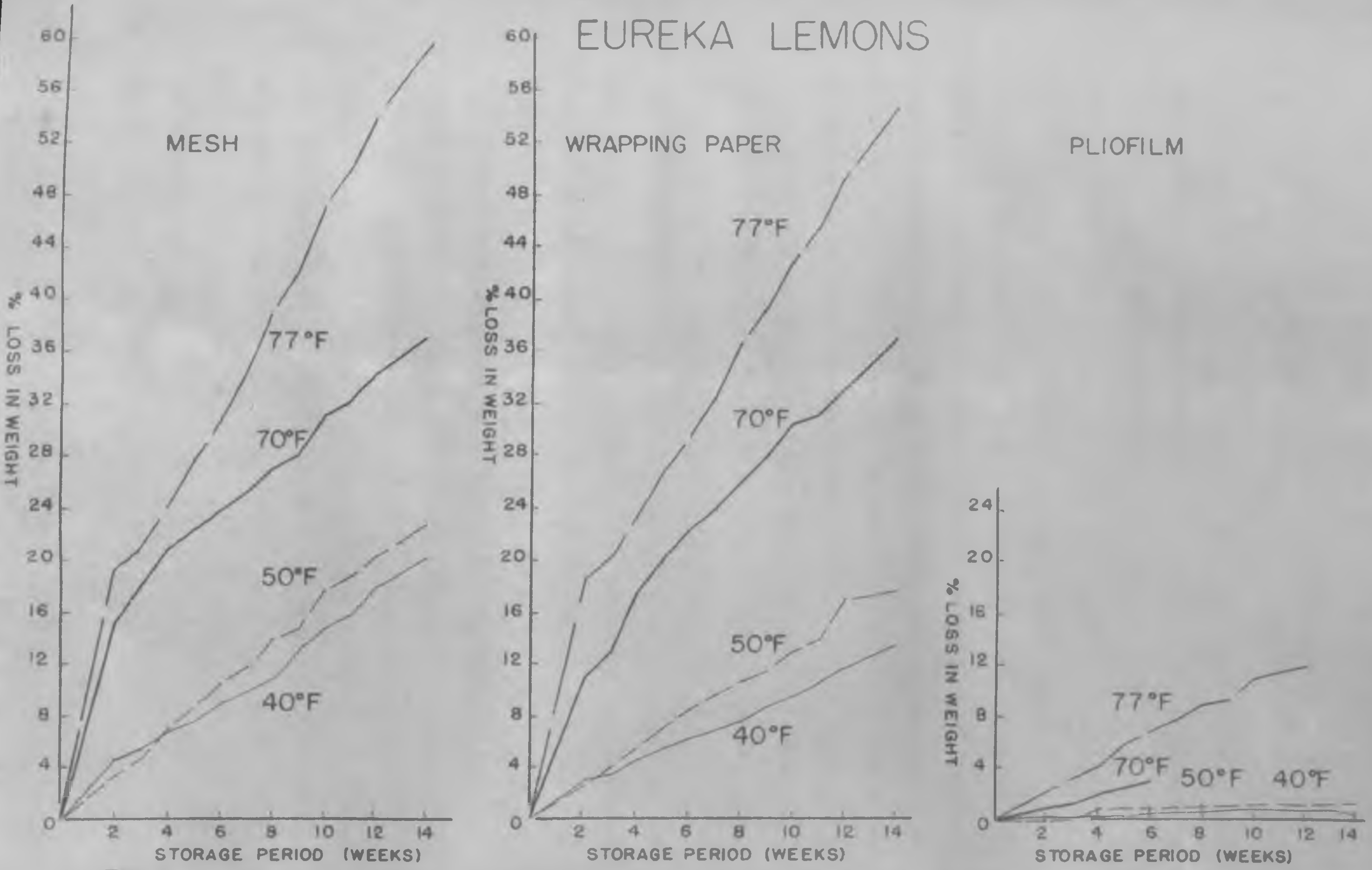

FIG IX PERCENT LOSS IN WEIGHT IN EUREKA LEMONS STORED AT VARIOUS TEMPERATURES IN DIFFERENT CONTAINERS AS AFFECTED BY THE LENGTH OF STORAGE PERIOD.

Other fruit measurements of the lemon also showed varying amounts of decrease in storage. Most of the decrease in volume occurred within the first 3 weeks, but was continuous during successive weeks. There was a correlation between rate of decrease in the measurements and the amount of moisture loss. The greater the loss in moisture, the more pronounced were decreases in volume, peel thickness, and diameters. In general, pliofilm and low temperatures had a marked effect in materially lessening the extent of decrease in these measurements.

Table XXX shows the effects of temperature, container, and length of storage period on volume, peel thickness, and diameters of the fruit.

Percent juice in terms of 100 grams of original weight also underwent a decrease. This loss was more pronounced by the 9th to 12th weeks. Higher temperatures as well as mesh bags were accelerating factors in loss of juice.

Table XXXI shows percent juice in fruit held at the different temperatures and in the various bags as affected by length of storage period. When percent juice is expressed in terms of fruit volume at time of analysis, there are indications of an increase during the first part of the storage period, followed by a decrease in the latter part. This is due to the greater loss of moisture from the peel at the beginning of storage, and also to the loss in juice during prolonged storage.

TABLE XXX

SOME PHYSICAL CHANGES IN EUREKA LEMON AS AFFECTED BY KIND OF CONTAINER AND LENGTH OF STORAGE PERIOD**

	Fruit volume %++			Peel thickness (mm.)			Axial diameter (mm.)			Equatorial diam. (mm.)		
Before storage	110.0			2.75			64.0			54.0		
Wks. in storage	M*	Wr+	P#	M*	Wr+	P#	M*	Wr+	P#	M*	Wr+	P#
					Stored at 40° F.							
3	98.0	90.5	102.0	2.0	2.5	2.75	61.2	60.6	65.4	49.2	50.0	50.6
6	70.0	90.5	101.0	1.75	1.5	2.5	61.4	57.8	66.2	57.8	47.4	51.6
9	79.0	90.5	101.0	1.25	1.25	2.75	62.0	61.4	66.0	47.4	48.2	52.0
12	87.0	79.0	98.0	1.5	1.25	2.5	61.4	57.6	67.0	47.2	46.6	50.6
					Stored at 50° F.							
3	96.0	94.0	106.0	2.0	2.0	2.75	63.6	63.4	65.0	5.0	49.8	51.2
6	98.0	92.5	105.0	1.25	1.75	2.75	63.4	64.3	64.0	58.4	49.0	49.4
9	99.0	81.5	95.0	1.75	1.5	2.5	61.2	64.5	64.0	49.6	48.6	49.6
12	90.5	85.5	93.0	1.5	2.0	2.75	60.0	64.0	64.0	47.0	48.8	50.4
					Stored at 70° F.							
3	77.0	77.0	93.0	1.0	1.0	2.25	60.6	60.8	64.0	49.2	49.2	49.0
6	70.0	73.0	90.0	1.0	1.0	2.5	57.0	61.8	66.0	48.2	49.2	50.2
9	75.0	77.0	86.0	.75	.75	2.25	57.2	61.0	65.0	47.0	48.6	50.1
12	72.0	75.0	87.0	1.0	1.0	1.75	59.4	61.0	61.6	46.6	48.0	49.6

TABLE XXX (cont.)

Wks. in storage	Fruit volume %++			Peel thickness (mm.)			Axial diameter (mm.)			Equatorial diam. (mm.)		
Before storage	110.0			2.75			64.0			54.0		
	M*	Wr+	P#	M*	Wr+	P#	M*	Wr+	P#	M*	Wr+	P#
	Stored at 77° F. (room)											
3	78.0	78.0	90.0	1.0	1.0	1.75	60.6	57.8	61.0	48.8	49.6	49.0
6	73.5	77.5	88.0	1.0	1.0	1.25	56.8	60.8	60.0	47.6	48.0	46.6
9	71.0	76.0	68.0	.75	1.0	1.0	57.6	60.6	60.25	47.2	48.5	45.75
12	71.0	75.0	67.0	1.0	1.0	1.0	57.0	60.4	56.6	47.4	47.5	45.2

**Values are average of 5 fruits
++Basis of 100 gms. original weight
*Fruit unwrapped and held in mesh bags
+Fruit paper-wrapped and held in mesh bags
#Fruit held in pliofilm bags

TABLE XXXI

EFFECT OF TEMPERATURE AND KIND OF CONTAINER ON PERCENT JUICE OF EUREKA LEMON

(Percent juice per 100 gms. of original weight)
Before storage 49.0

Wks. in storage	40° F. M*	40° F. Wr+	40° F. P#	50° F. M*	50° F. Wr+	50° F. P#	70° F. M*	70° F. Wr+	70° F. P#	77° F. (room) M*	77° F. (room) Wr+	77° F. (room) P#
3	39.0	40.0	47.0	45.0	43.5	47.0	43.0	43.0	45.5	40.5	42.0	45.0
6	38.5	38.0	49.5	44.0	43.0	49.0	43.0	42.0	46.0	35.5	32.5	44.0
9	40.0	35.5	46.0	40.0	35.0	47.0	34.0	33.0	45.0	25.0	22.0	25.4
12	39.0	40.0	44.0	39.0	33.0	46.5	26.0	35.0	40.0	16.0	14.7	30.0

*Fruit unwrapped and held in mesh bags
+Fruit paper-wrapped and held in mesh bags
#Fruit held in pliofilm bags

Chemical Changes

The data concerning the changes in percent acid of lemon juice from the various samples of fruit included in this test are summarized in Table XXXII.

It will be seen that percent acidity (mgs. per 100 cc. of juice) increased in storage, being greater from the lower to the higher temperatures. In other words, fruit held at 77° and 70° F. showed more increase in percent acid than that at 40 and 50°. While percent acid was 5.69 before storage, it became 8.35 percent by the end of the storage period at 77° in mesh bags, with intermediate values at other temperatures.

pH value remained about constant during storage, with a difference of only 0.3 between the maximum of 2.6 and the minimum of 2.3.

Percent soluble solid also showed an increase; the higher the temperature, the greater percent soluble solid (see Table XXXIII). Fruit held in pliofilm bags had less acid and soluble solid percents than that in other containers. This, of course, is due to the retention of moisture by pliofilm; consequently the solid constituents are more diluted than those in fruit held in mesh bags where the fruit is subjected to much dehydration and concentration of its solid constituents.

TABLE XXXII

CHANGES IN PERCENT ACID IN EUREKA LEMON
DURING STORAGE

Wks. in storage	Percent acid (citric per 100 cc. juice) Before storage 5.69		
	M*	Wr+	P#
		Stored at 40° F.	
3	6.10	5.90	5.85
6	6.70	6.42	6.18
9	6.10	6.65	6.59
12	6.00	6.20	6.45
		Stored at 50° F.	
3	5.47	5.79	5.89
6	6.35	6.35	6.00
9	6.15	6.05	6.58
12	6.10	6.57	6.00
		Stored at 70° F.	
3	6.40	6.45	6.35
6	6.50	6.96	6.42
9	7.55	7.85	7.05
12	8.30	8.05	8.00
		Stored at 77° F. (room)	
3	5.63	6.30	6.20
6	6.77	7.30	6.65
9	7.50	7.40	7.82
12	8.35	7.60	7.75

*Fruit unwrapped and held in mesh bags
2. Fruit paper-wrapped and held in mesh bags
#Fruit held in pliofilm bags

TABLE XXXIII

CHANGES IN PERCENT SOLUBLE SOLID AND SOLID/ACID RATIO OF EUREKA LEMON

Wks. in storage	Percent soluble solid (Basis 100 cc. juice) Before storage 7.87			Ratio solid/acid 13.80		
	M*	Wr+	P#	M*	Wr+	P#
			Stored at 40° F.			
3	8.73	8.80	8.73	1.43	1.49	1.49
6	8.70	8.73	8.60	1.30	1.36	1.39
9	8.07	8.73	8.73	1.32	1.31	1.32
12	8.87	9.40	8.73	1.47	1.51	1.35
			Stored at 50° F.			
3	9.27	9.27	9.33	1.69	1.60	1.58
6	8.73	8.80	8.73	1.37	1.38	1.45
9	8.80	9.27	8.80	1.43	1.53	1.33
12	9.07	9.47	8.87	1.49	1.44	1.48
			Stored at 70° F.			
3	10.07	9.47	9.07	1.57	1.47	1.42
6	9.73	9.47	8.87	1.49	1.37	1.38
9	10.13	10.73	10.40	1.35	1.37	1.33
12	10.60	10.73	10.27	1.28	1.34	1.29
			Stored at 77° F. (room)			
3	9.87	9.40	9.40	1.75	1.49	1.55
6	10.07	10.07	8.67	1.50	1.38	1.52
9	11.38	10.30	11.38	1.52	1.40	1.45
12	12.12	10.47	10.73	1.45	1.38	1.39

*Fruit unwrapped and held in mesh bags
+Fruit paper-wrapped and held in mesh bags
#Fruit held in pliofilm bags

Should solid and acid percents be calculated on the basis of 100 grams of original weight, they showed a decrease during storage. This is more pronounced in prolonged storage at the higher temperatures (see Table XXXIV). However, pliofilm prevented the rapid loss in soluble solid by slowing down the life activities of the fruit.

The solid/acid ratio (Table XXXIII) showed little change during the entire period. There is some indication, however, of an increase followed by a slight decrease with prolonged storage at any temperature and in any container.

Vitamin C percent (mgs. per 100 gms. original weight) showed a decrease during storage, which was most distinguishable at higher temperatures. Pliofilm, however, had a retarding effect on loss of the ascorbic acid constituent. Table XXXV summarizes vitamin C percent before and after 12 weeks in storage at 40° and 77° F. (room temperature) in both mesh and pliofilm. It is noticed that while about four-fifths of the vitamin was lost in mesh bags, only about one-half was lost in pliofilm bags.

Miscellaneous Observations

No taste determination was made for lemon juice since it is so acid the increase or decrease in its constituents would not show up in taste.

Color of rind and appearance of fruit corresponded to the amount of moisture loss. The more loss in moisture, the greater development of a duller shade, especially at the

TABLE XXIV

PROGRESSIVE CHANGES IN PERCENT SOLUBLE SOLID OF EUREKA LEMON WHILE HELD IN MESH BAGS

Wks. in storage	Percent soluble solid (Basis 100 gms. of original weight) Before storage 4.20	
	50° F.	77° F. (room)
3	4.15	4.00
6	4.25	3.58
9	3.44	2.84
12	3.62	1.94

TABLE XXXV

PERCENT VITAMIN C OF EUREKA LEMON BEFORE AND AFTER 12 WEEKS STORAGE

Temperature	Percent vitamin C (ascorbic acid) per 100 gms. of original weight Before storage 20.00	
	M*	P#
40° F.	13.40	15.80
77° F. (room)	4.85	9.60

*Fruit unwrapped and held in mesh bags
#Fruit held in pliofilm bags

higher temperatures.

Various degrees of off-shape resulted in the fruit. Shriveling around the stem and shrinkage of the peel always accompanied prolonged storage, their degree depending on temperature and kind of container. While low temperatures and pliofilm retarded these changes to a minimum, high temperatures and mesh bags accentuated the changes to a maximum. Hardening of the fruit was always present with excessive drying, especially after prolonged storage.

Pitting: Among the citrus varieties tested, lemon was found to be most susceptible to pitting, which was a detriment to the keeping quality of this fruit. Pitting developed even at 50°, which was high enough to prevent pitting in Marsh seedless grapefruit. In fact, none of the temperatures used in this experiment were suitable for storing the Eureka lemon. Fruit stored at 40 and 50° developed various degrees of pitting, and that held at higher temperatures was affected by varying amounts of decay.

Fruit held at 40° F. started to pit after only 3 weeks in mesh bags, with an increased amount of pitting during prolonged storage. At 50° the pitting was retarded to some extent. Tissue wrap helped materially in reducing this defect, while pliofilm had a marked effect in retarding pitting at 40° and in entirely preventing it at 50° F.

Figure X illustrates the effect of pliofilm in preserving the original good appearance of the lemon fruit after 4 months in storage at 50° F.

Decay: Blue and green molds, and alternaria rot were serious contaminations in the stored lemon fruit. The high temperature of 70° with high humidity (65 percent) was the worst storage environment so far as rotting was concerned, though at 40 and 50° there were slight contaminations with blue and green molds. Pliofilm was a favoring factor in the development of these diseases.

DISCUSSION

The ability to control changes occurring in citrus fruit during storage presents many advantages to the citrus industry. The two angles which were investigated in this study were the degree of temperature and the kind of container, both responsible for the acceleration or retardation of changes taking place in fruit during storage.

Effect of Temperature

Physical Changes

Results with the Marsh seedless grapefruit, Valencia orange, Naval orange, Algerian tangerine, and Eureka lemon show the same trends in regard to physical changes. The low temperature of 40° F. was slightly superior to 50° F.,

Figure X Eureka lemon after four months in storage at 50° F. in different containers.

and this in turn much superior to higher temperatures of 70° and 77° (room temperature). Not only was temperature responsible for the rapid change at the higher levels, but also the difference in humidity of the atmosphere (65 percent at 70° and 57 percent at 77°) had a marked effect on the rate of change in the fruit characteristics. The lower the humidity, the more change took place.

The various samples stored at any temperature all lost in weight, volume, and juice. There was also a decrease in diameter, both axial and equatorial, and in thickness of peel. The mean loss in weight and the decrease in the other values, however, were not the same for the different temperatures. While they were accelerated at higher temperatures (70 and 77°), they were slowed down to the minimum at lower temperatures (40 and 50° F.). This is because cold temperature lowers the vapor pressure of the water content of fruit so that the moisture loss is less rapid than would be the case at higher temperatures. These results correspond with findings of other investigators, with little difference in the rate of loss, depending on the experimental conditions of each worker.

Percent juice on the basis of volume of fruit at the time of analysis showed an increase in some cases, or an increase followed by a decline with prolonged storage in other cases. The increase in juice percentage is due to the more rapid loss in moisture from the peel rather than the loss from the juice, especially at the beginning of the storage period (17).

Chemical Changes

All chemical changes were accentuated by high temperature and retarded by low.

Titratable acidity: Acid percentage showed an increase in the Marsh seedless grapefruit, Naval orange, Algerian tangerine, and Eureka lemon during storage. The increase was greatest at high temperatures and less at low. These results do not interfere with the results of Hawkins and Magness (14) or Stahl and Camp (27). They mentioned that percent acid increased at high temperatures (55, 70, 86° F.) and decreased at low temperatures. The slight increase which developed at 40° in this study can be attributed to the fact that this is higher than the cold temperature they used (31-32° F.) and thus reacted as to the higher temperatures.

The same reason can also explain the results of Zoller (33) who noted a decrease in percent acid during storage of grapefruit. Brately (2) stated that there was a decrease in total acid during storage of Dancy tangerines at temperatures close to 40 and 50°. This is what would have happened if more fruits had been used in this experiment and the amount of acid determined per-fruit instead of in percentage. The increase in percent acid is mostly related to its concentration in the juice due to moisture loss. There is a probability, however, that the actual amount of acid increases in storage (14).

Percent of acid in Valencia oranges showed an increase at the beginning of the period, followed by a decrease with prolonged storage. These results correspond with those of Martin (17) on Marsh seedless grapefruit stored at 60° F.

Total soluble solids: At lower temperatures (40-50°) percent soluble solid showed an increase during the first 6 weeks in storage, followed by a decrease during the successive weeks. This is true with Marsh seedless grapefruit, Valencia and Naval oranges, and thus corresponds with the findings of Martin on his work with Arizona grapefruit (17). At higher temperatures (70 and 77° F.) the soluble solid percent showed a continuous increase, due to the progressive concentration of the solid materials in the juice.

In Algerian tangerine and Eureka lemon, the percent solid showed a continuous increase in storage at both high and low temperatures. It seems these two varieties have lost too much of their moisture content by dehydration (indicated by the rate in loss of weight), so that the solid materials were highly concentrated in the juice. There is a probability, however, that the pectins and hemicelluloses in the cell walls may break down to sugars (18). Percents of solid and acid on the basis of 100 grams of original weight showed a progressive decrease at any of the temperatures used, due to life activities of the fruit in storage.

The trends were the same in any container with respect to acid and solid changes. Fruit in pliofilm, however, showed lower acid and solid percents, due to the effect of the film in preserving moisture and the consequent dilution of the solid components of fruit.

In general, solid/acid ratio showed an increase in storage in all bags at all temperatures, probably due to the preferential use of acid in respiration (17, 33). In some cases, however, it showed a decrease, especially with prolonged storage. Whether this decrease is due to variation among individual samples or whether there is a shift from acid preferential in respiration to other soluble materials is not quite understood.

pH value did not show any significant difference in storage. The reason that pH value did not correspond with the changes in titratable acidity can be traced to the large buffer capacity of citrus juices. Citrus juice contains organic acids of low degree of dissociation. Weak acids can undergo considerable dilution without any great change in pH value. The dissociation of citrus acids is small, and the undissociated residue is sufficiently high to keep pH value about constant. In other words, the dilution or concentration of citrus juice by adding or subtracting water may change considerably the free acid (titratable acidity) yet the pH is not changed (1, 25).

Percent vitamin C (ascorbic acid), unless it remained about constant, showed a slight decrease in storage (5). See Appendix B. When vitamin C is expressed on the basis of 100 grams of original weight, however, it showed a pronounced decrease with prolonged storage (7); the decrease was proportional to the degree of temperature and length of storage period. The higher the temperature and the longer the fruit was held in storage, the more loss in vitamin C constituents occurred (2). This is due, of course, to ascorbic acid's being a strong reducing agent and thus easily lost by oxidation.

It should always be borne in mind that no two kinds of fruit have the same chemical constituents, nor do two samples of the same kind of fruit. The variation among individual samples might have an effect on the results.

Other Characteristics

Taste of fruit was always in agreement with the solid/acid ratio. The higher the ratio, the greater tendency was shown toward development of a flat taste. The lower the ratio, the more tendency toward development of an acid taste. Bitterness in grapefruit, however, was not intensified at low temperatures but was very noticeable at high temperatures. The taste of Valencia orange and Algerian tangerine was not affected at lower temperatures, though the Naval orange did develop various degrees of staleness probably because temperatures of 40-50° F. are rather high for their storage.

Shriveling of fruit, with subsequent deepening of color and hardening, always accompanied excessive drying. This was true for all varieties of citrus at temperatures of 70 and 77°. At lower temperatures of 40 and 50°, the fruit showed slight wilting accompanied by various degrees of off-shape, especially under prolonged storage.

Eureka lemon was the most susceptible to pitting. While pitting was serious in grapefruit at 40°, it was more so in the lemon at both 40 and 50° (18). Naval oranges did not show pitting except at the end of the storage period and when held at 40° F. Valencia orange and Algerian tangerine were not susceptible to this defect at any of the temperatures used in this study (29).

Blue and green molds were the serious decays encountered in the stored fruit. These were most serious in the Marsh grapefruit and Naval orange, especially at higher temperatures. Alternaria decay was prevalent in the lemon and tangerine; and there were a few instances of stem end rot decay on grapefruit, and sour rot in tangerine and lemon.

Effect of Kind of Container

Pliofilm was effective in materially reducing loss of moisture; hence it retarded loss in weighr, volume, diameters, peel thickness, and juice constituents. It also proved valuable in preserving the appearance of the fruit and in retarding any physical changes which might interfere with marketability.

Tissue-wrap had very slight effect in reducing the changes taking place during storage.

So far as chemical changes were concerned, there was no appreciable difference between fruit held in mesh bags or that tissue-wrapped; that is, there was no difference which would exceed that attributable to individual variation. Pliofilm had noticeable effects. Its retention of moisture aided in diluting the solid constituents, and thus the fruit showed less acid and soluble percents than did fruit held in other containers. Pliofilm also proved efficient in retarding loss of soluble solid and ascorbic acid. This may be due partly to the film which allows some accumulation of CO_2 gas, so that the oxygen is reduced and the oxidation process retarded. In some cases, as with Marsh grapefruit and Naval orange, this condition impaired taste so that the fruit tasted more stale; it did not have such an effect on the Valencia orange or the tangerine (24).

Use of pliofilm bags also had a tendency toward development of a flat taste, due to the higher solid/acid ratio of such fruit in comparison with fruit held in other bags. This probably is due to the preferential use of acid in respiration and the relatively limited amount of oxygen in the film, which resulted in less oxidation of other soluble constituents than of acid.

Pitting was retarded materially or entirely prevented by the use of pliofilm bags, probably because this material contains a substance which may absorb the esters that cause pitting (28). The question of whether this is the reason or whether it is due to the small amount of accumulated CO_2 gas in the film needs further investigation.

The greatest disadvantage in the use of pliofilm bags seems to be that they build up moisture, thus encouraging fruit decay. This probably could be overcome to some extent by greater sanitary measures.

SUMMARY AND CONCLUSIONS

The effect of storing Arizona citrus fruit at 4 different temperatures and in 3 different types of containers was studied. The results can be summarized as follows:

1. The <u>kind of container</u> is as important as the degree of temperature, especially in retarding or accelerating loss in weight and in other changes taking place during storage. While the low temperature of 40° F. reduced the loss in weight which occurred at the high temperature of 70° by about half, pliofilm bags at 40° reduced this loss to about one-fifth that in mesh bags at the same temperature and after the same storage period (3 weeks). Likewise the decrease in volume, diameters, peel thickness, and juice constituents was retarded at low temperatures and by the use of pliofilm bags.

The longer the fruit was in storage, the greater changes took place in all these characteristics; yet the percent of juice per fruit volume generally increased. This is due to the rapid loss of moisture from the peel.

2. The Marsh seedless grapefruit showed an increase in acid percent at all temperatures, but was accelerated at higher temperatures. Soluble solid percent likewise showed an increase at higher temperatures (70 and 77°), and an increase followed by a decrease at lower temperatures (40 and 50° F.).

The solid/acid ratio showed an increase, followed by a slight decrease with prolonged storage.

When percents of solid and acid and vitamin C are expressed on the basis of 100 grams of original weight of fruit, they showed decreasing values in storage. The loss in these constituents caused by the respiration and oxidation processes was retarded at lower temperatures. pH value did not show any significant change in storage, due to the large buffer capacity of citrus juices.

Pitting manifested itself in the grapefruit at 40° but did not show at 50° F.

Decay and most penicillium molds were serious at the higher temperature of 70° with relative humidity of 65 percent; wilting of fruit was serious at room temperature (77°) with low relative humidity of 57 percent.

The temperature of 50° proved superior to other temperatures for the storage of Marsh grapefruit, especially when the fruit was held in pliofilm bags. Under these conditions the fruit stored satisfactorily for 4 months.

3. In Valencia orange the percent acid and solid showed an increase at the beginning of the storage period, followed by a decrease with prolonged storage. The solid/acid ratio decreased slightly, with the exception of fruit held at room temperature which showed an increase in this ratio.

The Valencia orange was resistant to pitting at the lowest temperature (40°), and decay was not serious. In all other respects, this fruit reacted as did the grapefruit.

For the storage of Valencia orange, 40 and 50° gave the most satisfactory results, with no appreciable difference between temperatures. This orange was the citrus variety best adapted to cold storage for a long period, especially when held in pliofilm bags. Physically, this fruit stored satisfactorily for 11 months.

4. In the Naval orange the acid percent increased at any temperature used. Soluble solids increased at the higher temperatures, and showed an increase followed by a decrease at the lower; this was the same reaction found in grapefruit. The solid/acid ratio showed an increase during the first weeks in storage, and remained about constant or decreased slightly in successive weeks. In other respects, this orange reacted as did the grapefruit.

Pitting did not develop at 40° F. but was slightly noticeable at the end of the storage period. Decay, especially the green and blue molds, was serious at high temperatures but was much eliminated at 40°. The Naval orange is probably the citrus variety whose taste is most adversely affected in storage, regardless of temperature used. Even under optimum storage conditions, this orange developed off-flavor; its physical appearance under optimum storage conditions was satisfactory at 4 months.

5. In the Algerian tangerine the percents of acid and soluble solid increased. The solid/acid ratio showed an increase during the first few weeks of storage, remaining about constant at low temperatures or increasing slightly in successive weeks at high temperatures. Other changes were similar to those in the other citrus varieties.

Pitting was not a factor, and did not show up at any temperature or after any length of time.

Alternaria decay was the disease encountered in stored Algerian tangerines. If this decay, along with penicillium molds, could be eliminated before storing, the tangerine should be well adapted to storage at 40° as well as at 50° for relatively long periods. The low temperatures, along with the use of pliofilm bags, did not have any deteriorating effect on the taste. In contrast to Naval oranges, the tangerine seems to keep its good taste even after storage for

4 months in pliofilm bags at 50° F.

6. The Eureka lemon showed a progressive increase in acid and solid percents during storage. The ratio of solid/acid showed an increase, which remained constant or decreased slightly. Other chemical changes were similar to those in other citrus varieties.

Pitting was a limiting factor for the storage of the Eureka lemon at 40 and 50°; also, alternaria decay was serious at 70° while dehydration and wilting were noticeable at 77°. In fact, none of the temperatures used in this experiment gave satisfactory results for the storage of lemons, except at 50° and in pliofilm bags. Under these conditions, the fruit kept its original appearance without deterioration for 4 months.

7. The use of pliofilm bags had many advantages. Outstanding was the reduction in loss of juice constituents and of moisture, though loss in soluble solid and vitamin C also was remarkably retarded. The percents of acid and solid were less in fruit held in pliofilm bags than in other types, due to the dilution of the constituents in the film bag. The solid/acid ratio increased in the film at any temperature and in any citrus variety, but was higher in the pliofilm bags than in other containers. Also, fruit held in the film developed a flat taste.

Plio film also had a very marked effect in reducing pitting, and entirely prevented it in Eureka lemons stored at 50°.

The greatest disadvantage in using pliofilm for storing citrus fruit was its tendency to encourage decay, because it retained moisture so effectively. The film also allowed only a small accumulation of CO_2 gas, which intensified the stale taste.

This pliofilm is highly recommended for the storage of citrus fruit, but care must be taken to use the proper gauge or off-flavors may result. Also, extra precautions need to be taken in sanitation measures to prevent molds.

8. The tissue-wrap had little effect in retaining moisture, hence is of small value in retarding weight loss and other changes. There was no substantial difference in the chemical content of fruit tissue-wrapped and that held in mesh bags unwrapped. Tissue-wrap did have a slight effect in reducing pitting, and it may be recommended for citrus fruit storage for short periods of time.

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TABLE XXXVI - APPENDIX A

pH VALUES OF DIFFERENT VARIETIES OF CITRUS FRUIT HELD IN MESH BAGS

Wks. in storage		Marsh seedless grapefruit	Valencia orange	Naval orange	Algerian tangerine	Eureka lemon
	Before storage	3.20	3.90	4.00	3.55	2.55
			Stored at 40° F			
3*		3.25	4.00	3.80	3.50	2.50
6		3.00	3.90	3.60	3.50	3.25
9		3.25	3.85	3.80	3.65	2.60
12		3.20	3.80	3.85	3.60	2.40
			Stored at 50° F.			
3		3.30	3.80	4.00	3.60	2.60
6		3.10	3.80	3.75	3.05	2.40
9		3.25	4.00	4.00	3.50	2.50
12		3.20	3.80	3.90	3.50	2.65
			Stored at 70° F.			
3		3.20	3.90	3.90	3.40	2.50
6		3.10	3.80	3.85	3.30	2.30
9		3.25	3.80	4.00	3.50	2.60
12		3.15	3.90	4.00	3.55	2.55
			Stored at 77° F. (room)**			
3		3.20	4.00	3.90	3.50	2.50
6		3.10	3.90	4.10	3.50	2.45
9		3.30	3.90	4.00	3.50	2.60
12		3.25	3.80	3.90	3.55	2.55

*With the exception of Valencia orange for which values were taken at 2-week intervals. **Room temperature for Valencia orange was 84° F.

TABLE XXXVII - APPENDIX B

PERCENT VITAMIN C++ OF CITRUS FRUIT BEFORE AND AFTER 12 WEEKS STORAGE

Variety	Before storage	Stored at 40° F.		Stored at 77° F.	
		M*	P#	M*	P#
Marsh seedless grapefruit	41.50	42.0	40.5	43.0	40.5
Valencia orange	50.90	53.6	49.3	55.5	50.0
Naval orange	54.0	49.8	54.9	44.8	44.8
Algerian tangerine	55.8	52.7	57.6	94.0	48.2
Eureka lemon	41.2	34.6	35.9	30.3	32.0

++On basis of 100 cc. of juice
*Fruits unwrapped and held in mesh bags
#Fruit held in pliofilm bags