Refrigerated and frozen storage
Concentrating
Dehydrating
Pickling and fermenting
Sugar preservation
Miscellaneous
Recovery of constituents
Disposal of residues and effluents
Analytical and composition
Nutrition
Still another basis for classification might be according to the type of food as:
Fruits
Vegetables
Grains
Nuts
Spices
Meat
Fish
Dairy products
Poultry products
Condiments

Confections
Beverages.

A system based upon the chemical constituents of foods such as, “Carbohydrates, oils, fats, waxes, nitrogen compounds, etc.,” would appear to have little practical value to food technologists, and would probably result in increasing the difficulty of surveying current technical literature.

It is no simple problem, but one which, along with the research projects, may profitably be considered and discussed in the interest of solving problems of using our food crops to the best of advantage.

Acknowledgment: While all opinions expressed in this article are the author’s own, he wishes to express his appreciation of suggestions made by members of the Citrus Products Research Council and by H. W. von Loeseke formerly in charge of the U. S. Citrus Products Station at Winter Haven, Florida.

---

THE PHYSIOLOGY OF CITRUS FRUITS IN STORAGE*

ERSTON V. MILLER
Division of Fruit and Vegetable Crops and Diseases, Bureau of Plant Industry, Soils and Agricultural Engineering, U. S. Dept. of Agriculture, Orlando

Introduction

Citrus fruits are not held in cold storage to the same extent as are deciduous fruits. The latter must be removed from the tree before they become overripe, while citrus fruits, on the other hand, are usually “stored” on the tree until marketed. However, there are several exceptions to this statement. When oranges and grapefruit are delivered to the metropolitan areas in quantities too large for immediate consumption, they have to be held in cold storage. In Florida the commercial season for shipping oranges usually terminates about June 1. While it is true that up to this time oranges are held on the tree until marketed, many types of oranges tend to dry out and re-green with the advent of warm weather and could therefore be held much more advantageously in cold storage. This might serve to extend the marketing season into the summer months.

In other parts of this country and in foreign countries citrus fruits have been exposed

---

*This paper is a digest of a longer article covering the same subject which is being written for the Botanical Review.
to low temperatures either in storage or in transportation and quite a bit of information has been accumulated on the behavior of these fruits in storage. The object of this paper is to attempt to summarize insofar as possible the results of the research on this subject.

Changes Occurring During Ripening
A better understanding of the storage life of citrus fruits may be had if consideration is first given to a little of the pre-storage life.

According to Harding, Winston, and Fisher, when oranges ripen there occurs a gradual increase in total soluble solids (principally sugars) and a decrease in acids. Concentration of the vitamin C in the juice decreases slightly, but at the same time the volume of juice is increasing. Actually, therefore, the amount of vitamin C per orange increases with ripening. Other changes accompanying ripening are increases in size, weight, and volume of juice, as well as a change from a green to yellow color in the rind. Oranges do not undergo a softening during ripening, as is characteristic of such fruits as apple, peach, pear and banana, and they do not ripen after removal from the tree. What has been said concerning the ripening of oranges applies also to other types of citrus fruits.

Changes Occurring After Harvest
If citrus fruits are held too long at relatively high temperatures following harvest they may be attacked by decay-producing organisms or may undergo changes which render them less attractive, less palatable, and less nutritious. The blue mold and stem-end decays are all too common to require description here in any detail. If the fruit does not decay, it will lose water and become shriveled. In due time, too, there will occur a loss in sugar, acids, vitamin C, and some of the other substances which impart flavor or aroma to the fruit.

Effect of Cold Storage On Changes In Citrus Fruits
The object of cold storage is to retard the changes which occur rather rapidly at ordinary living-room temperatures. To any person who has had experience with the cold storage of fruits and vegetables, it is quite obvious that growth of the organisms causing decay is arrested by the use of low temperatures. But what about the other changes which are chemical or physical in nature? Experience has shown that loss of water or shriveling may be prevented by maintaining high enough relative humidity in cold storage as well as by the application of a moderately heavy coating of wax on the fruits or by the use of fairly moisture-proof wrappers or box-liners.

Investigators all over the world have reported that oranges, lemons, grapefruit, and tangerines show a slight loss in acids in cold storage but no significant changes in sugar. Likewise no significant changes in vitamin C have been reported except in tangerines. Oranges have been stored for as long as three months without loss of vitamin C and the antiscorbutic value of lemons has been stated to remain unimpaired so long as the fruit remains in good condition. As early as 1921 Hawkins reported that grapefruit in storage lost some of the bitter principle (naringin) and that as a result of this and the loss of acids, the flavor of grapefruit was improved by cold storage. A number of years later Harvey in California showed that naringin in the rinds of grapefruit decreased in storage if the fruit was grown in the areas where harvest follows a cool period, but that this substance increases in the fruit harvested following a hot, dry summer. Cold storage of lemons produces a slight reduction in the materials that make up the cell wall structure.

Respiration
In discussing the physiology of fruits it should be borne in mind that a fruit continues to live even after removal from the tree. It absorbs oxygen, burns up sugar and acids, and releases carbon dioxide and heat. This process is called respiration.

The rate of respiration of citrus fruits is lower than that for many other fruits. At 32° F, for example, the rate for oranges is similar to that of the low-respiring deciduous
fruits (apples and pears) while for lemons and grapefruit the rate is still lower than for oranges.

Oranges are like certain other fruits in that they experience a "climacteric" in respiration. Beginning at the time fruits are usually harvested the rate of respiration increases slowly until a peak is reached, following which the rate drops off gradually and the fruit passes into senescence or old age. The peak in respiratory rate is called the "climacteric." It has been reported from Australia that the storage life of oranges may be extended by storing them prior to the development of the respiratory climacteric and that the longer the interval before the climacteric appears, the longer the fruit may be stored without the development of a serious percentage of decay. On the other hand, some of the physiological disorders seem to be related to the development of the climacteric after the fruits have been stored. It has been reported, for example, that more rind breakdown develops in citrus fruits picked early and placed in cold storage than in fruits harvested near the end of the commercial picking season, which have apparently passed their respiratory climacteric.

Description of Physiological Disorders Occurring In Cold Storage

It must not be overlooked that certain difficulties may be encountered in the cold storage of citrus fruits. These are physiological disorders which may develop if the fruits are held in storage too long or if stored at the wrong temperature. Before discussing the occurrence of these disorders, brief descriptions of the several types will be presented.

Pitting: Pitting consists of abruptly sunken spots in the rind. The spots, though not discolored at first, may later become slightly pink on grapefruit and eventually brown on both grapefruit and oranges. Although pitting may occur at the time of packing or in transit, it generally does not develop until after a storage period of four to six weeks. Pits on lemons usually appear as depressed areas in the rind, from 1/16 to 1/2 inch in diameter, sometimes retaining their natural color but more often becoming dark brown, approaching black. A similar type of rind breakdown in limes is not referred to as pitting because large areas are usually involved, and they are more irregular in shape.

Watery breakdown: Watery breakdown gives the appearance to the fruit of having been frozen. Fruits are soft and spongy and have a water-soaked appearance.

Brown stain or scald: Brown stain or scald of oranges consists in a superficial and uniform browning over relatively large areas of the rind, differing from pitting in the large areas affected and in not being sharply depressed.

Aging: Aging is sometimes found on oranges and grapefruit after harvest. The rind around the stem button or upper part of the fruit becomes wilted or shriveled, with or without collapse of the rind tissue.

Membranous stain or membranosis: Membranous stain or membranosis of lemons is characterized by a browning or darkening of the membranes or carpellary walls between segments, sometimes affecting the inner core tissues and inner tissues of the rind.

Albedo browning: Albedo browning of lemons takes the form of a discoloring of the white, spongy, inner part of the rind which is known as the "albedo.”

Peteca and red blotch: Peteca and red blotch are two superficial blemishes of the rind of lemons, the former consisting of slight, pit-like depressions and the latter being a scald-like surface browning.

The Development of Physiological Disorders In Storage

Investigators throughout the world have not always agreed on the exact temperature at which these disorders are most likely to occur, and it is possible that differences in results may have been influenced by factors other than cold storage. As a rule, however, pitting and aging in grapefruit are generally most pronounced at 40° F., and 36° to 40° F. appears to be the critical range in temperature for oranges. Watery breakdown and scald are most likely to be found in fruit stored too long at 32° F. or lower,
and it is believed by some workers that appearance of this disorder at 32° may be the result of an accidental drop in temperature, temporarily at least. In the storage of lemons, 32° to 40° is not recommended. Pitting is usually more pronounced at 32° to 36° F., red blotch at 36° to 40° F., and membranous stain is worse at 40° F than at higher or lower temperatures. Watery breakdown in lemons occurs at 32° F, as is the case with oranges and grapefruit. Key (Mexican) and Tahiti (Persian) limes are subject to rind breakdown at 40° F. although they will also develop this disorder if held long (eight weeks) at 45° F.

Factors Affecting the Incidence of Physiological Disorders

Although the physiological disorders previously mentioned are usually referred to as low temperature injuries, there are certain other factors which, though not directly responsible for the injuries, certainly exert a direct influence on the fruits' susceptibility to low temperature breakdown. It has been observed in Florida, for instance, that oranges and grapefruit produced in the low hammocks are more liable to breakdown in cold storage than is the fruit produced on the high pine lands. It has been reported in Texas that grapefruit from trees receiving a high percentage of potash in the fertilizer has shown more physiological breakdown in storage than that from unfertilized trees. In South Africa grapefruit picked from the outside of the tree was found to be more susceptible to injury in cold storage than was that from the inside. Variety is another factor in susceptibility to physiological disorder. In the U. S. A. the early and midseason oranges as a rule are more susceptible to pitting than are the late-ripening varieties. The Pineapple orange is the most susceptible variety. A number of investigators have reported that seedy varieties of grapefruit may be more satisfactorily stored than the seedless varieties.

Stage of physiological maturity should be considered in the storage of citrus fruits. By physiological maturity is meant the age with reference to the respirational climacteric. It is believed by some that the physiological disorders occur in storage just after the fruit has experienced its respirational climacteric. A low relative humidity in the storage rooms is another factor that is conducive to the development of pitting on oranges, lemons, and grapefruit. Furthermore, the storage life of citrus fruits is definitely affected by the amount of handling the fruit has received prior to storage. Winston and Roberts have conducted experiments on this subject and report that: "The washing, color-adding, ethylene, and waxing treatments given oranges in packing houses increased rind breakdown considerably. All steps appeared to contribute to the increase."

Methods for Preventing Physiological Disorders in Storage

One of the earliest methods tried for the prevention of low temperature injury in grapefruit consisted of a pre-storage "curing." Grapefruit were held at 70° to 75° F. for two weeks prior to storage. Later it was found possible to shorten the curing period to three to five days and to reduce the temperature to 65° F. Most of the experiments with pre-storage curing of grapefruit have been conducted in South Africa where it has been placed on a more or less quantitative basis. However, the pre-storage curing of grapefruit has not been adopted as a regular practice in the industry of any country. Curing of oranges has not proved successful.

Another method for preventing cold storage deterioration in citrus fruits consists of adding a moisture-proof covering. Both waxes and wrappers have been tried, and the latter have proved a little more satisfactory. Success has been reported with the use of moisture-proof and semi-moisture-proof cellophane, pliofilm, and aluminum foil.

Carbon Dioxide Storage

Carbon dioxide has been added to the storage atmosphere of citrus fruits for the purpose of lengthening the storage life both by reducing decay and by preventing physiological disorders. Attempts at the first have usually resulted in development of rind injury
or a bitter flavor in the pulp. This no doubt was due to the use of too high concentrations of carbon dioxide or to too long a period of storage in the gas. Some success has been reported by workers using 6 percent carbon dioxide and 12 percent oxygen.

A few workers have reported preventing physiological disorders by exposing citrus fruits to high concentrations of carbon dioxide for relatively short intervals before storage. However, carbon dioxide storage of citrus fruits is still in the experimental stage.

**Ethylene**

Ethylene is mentioned in a discussion of this kind, not only because it has been shown to exert a definite effect on the subsequent storage life of the fruit but also because it plays an important role in the physiology of citrus fruits in more ways than one.

When citrus fruits were shipped to the Northern markets at the turn of the century, it was customary to prevent freezing by installing kerosene stoves in the cars. It was noted that during transit the fruits assumed the characteristic orange color, and it was assumed that this was merely a ripening process due to the heat generated. In 1921 it was shown that the active coloring agent was to be found in the exhaust fumes of the kerosene stove and was not due to heat. In 1924 it was found that the active agent in kerosene fumes was an unsaturated hydrocarbon and when ethylene gas was tried, it worked as well as the stove gas, if not better. Ethylene treatment is now a commercial practice and has been used for years without anyone's ever proving that it was this gas and no other in the fumes of the stove.

Ethylene treatment definitely affects the storage life of citrus fruits in that it has been reported to increase the amount of pitting and aging of oranges, and red blotch, albedo browning, and to some extent membraneous stain in lemons, and to accelerate decay in oranges, tangerines, grapefruit, lemons, and limes.

Interest in the ethylene was revived among physiologists when it was discovered that this gas was evolved by fruits and vegetables as a product of normal metabolic activity. This was first reported in experiments with apples but was later found to be true for citrus fruits and in addition it was found that decaying fruits evolve the gas more rapidly than normal fruits. In recent years also reports have been published of the many peculiar physiologic effects that ethylene produces upon other fruits and vegetables in storage. This, together with the many other facts reported in this paper, indicate that proper storage of citrus as well as any other fruits and vegetables involves a knowledge of plant physiology and the many physiological problems involved.

**Conclusion**

In this paper an attempt has been made to present the results of research on the physiology of citrus fruits in storage, and, although reports from various parts of the world have been examined, it is realized that the review is far from complete. It is realized also that the grower and shipper of citrus fruits is interested primarily in obtaining definite recommendations regarding the proper temperature for storage of citrus fruits and the maximum period that they may be held in cold storage. The above suggestions, based

<table>
<thead>
<tr>
<th>Fruit</th>
<th>Recommended Temperature</th>
<th>Relative Humidity</th>
<th>Duration of Storage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grapefruit (grown in regions where stem-end rot is prevalent)</td>
<td>32-34</td>
<td>85-90%</td>
<td>6 to 8 weeks</td>
</tr>
<tr>
<td>Grapefruit (from regions where stem-end rot is not prevalent)</td>
<td>45-55</td>
<td>85-90%</td>
<td>6 to 8 weeks</td>
</tr>
<tr>
<td>Oranges</td>
<td>34-38</td>
<td>85-90%</td>
<td>8 to 10 weeks</td>
</tr>
<tr>
<td>Lemons</td>
<td>55-58</td>
<td>85-90%</td>
<td>1 to 4 mo.</td>
</tr>
<tr>
<td>Limes</td>
<td>45-48</td>
<td>85-90%</td>
<td>6 to 8 weeks</td>
</tr>
</tbody>
</table>
on recommendations of the U. S. Department of Agriculture (Circular 278) are therefore included in this paper.

As mentioned previously in this paper, the life of citrus fruits in storage may depend upon several factors. Several investigators have reported storing oranges and grapefruit for periods longer than those recommended in this paper. It is possible, too, that certain individual crops may not have as long a storage life as could be expected on the average. It should be remembered that increasing the period of cold storage of citrus fruits correspondingly shortens the period in which the fruit will remain marketable following removal from storage. A regular inspection of all citrus fruits in storage is urged if at all possible, and the life expectancy may be determined by the appearance of the fruit at the time of inspection.

---

RESEARCH IN HORTICULTURE DURING THE PAST YEAR BY THE FLORIDA AGRICULTURAL EXPERIMENT STATION

HAROLD MOWRY

Florida Agricultural Experiment Station, Gainesville

Working under war-time handicaps and strain which have been as serious and as problematical to them as the difficulties which the farmers and growers they are serving have had to face, the research staff of the Agricultural Experiment Stations has achieved much in agricultural research as have the growers in agricultural production.

Station men feel that the past year has been a very trying one, but they also feel with a modest pride of which they hope growers will approve that it also has been a year of notable accomplishment in horticultural research. Now that peace has come again, they look forward with high hope, energy, and imagination to performing even greater service for Florida growers.

In reviewing Station research of particular significance to horticulture during the past year, it is necessary to point out immediately that the projects that are listed are representative and not inclusive, and that the completion of most research projects is not accomplished within the short span of a year. In fact, most research achievement is the result of several or many years of work and endeavor, with a great deal of routine but necessary and faithful effort involved in the ultimate accomplishment.

Vegetables

One of the most sensational developments in Station research during the past year was the success which attended the application by potato growers in southern Florida of the Dithane-zinc sulphate-lime spray. Used on 95 percent of the potato acreage, it proved highly effective in controlling blights, and it and good growing weather were responsible for the highest yields on record in that section.

Marked progress was made against that bane of tomato growers—Fusarium wilt. Studies and field tests which began several years ago resulted in development of several strains which proved immune to wilt in the field. The best of these will be given further tests for yield and quality, and seed will probably be released for market within the next year.

Comprehensive analyses revealed that vegetables grown in Florida compare very favorably with those grown in other states in vitamin content. This research showed that the