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Cold Storage for Tropical Fruits

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INTRODUCTION.

So far as may be judged by the literature on cold storage available to this station, no systematic experiments have been made in cold storage of tropical fruits except citrus fruits and bananas. Even with these fruits experiments have been largely confined to a study of the proper temperatures to apply during transportation. Benson* reported that mangos and pineapples could be safely held in cold storage for four to six weeks, but that passion fruit could not keep more than two weeks in cold storage. At various times this station has made tests which indicated that mangos and avocados would preserve their flavor and texture for four to six weeks in a commercial refrigeration room for fruit.

The supply of tropical fruit on the Honolulu market is irregular. The market is sometimes flooded and sometimes bare. The station is attempting, through its marketing division, to adjust the supply of fruit more uniformly to the demand. It became necessary to know, however, whether cold storage was applicable to tropical fruits as it is to apples, pears, etc. Through the courtesy of the Hawaiian Electric Company, the station was offered the use, for

* Agr. Gaz. N. S. W. 4 (1893) pp. 870-877.

experimental purposes, of several refrigerator rooms maintained at different temperatures. In the experiments reported in this bulletin a study was made of the effect of cold storage on star apple (*Chrysophyllum cainito*), avocado, fig, papaya, water lemon (*Passiflora laurifolia*), strawberry guava, pineapple, and mango, and also upon the eggs and larvae of Mediterranean fruit fly in these fruits. It was considered important to determine the degree of refrigeration and length of time required to kill this pest, particularly in mangos and avocados.

TEMPERATURE OF THE REFRIGERATION ROOMS.

Throughout the six months occupied by the experiments, the temperature of each room remained very uniform. The temperatures reported in the following pages are the average temperatures for the whole period. In the 32° room the temperature ranged from 30° to 33°; in the 36° room, from 33° to 38° F.; and in the 45°, from 40° to 47°. Continuous thermograph records were kept, and checked by certified thermometers. The air was reasonably dry in all three rooms.

STAR APPLE.

Large purple, small purple and green varieties of star apple were used, 73 fruits in all. Of these fruits 33 were held at a temperature of 32° F. and 40 at 45° F. All but 11 of the fruits had been bagged on the trees to prevent infestation with fruit flies. The uninfested fruit was cured two days in a fruit room at the station before being placed in cold storage.

Four large purple star apples picked in a green condition, showed slight shriveling of the skin after being held six days at a temperature of 32° F. No other noticeable changes took place during the next 50 days, at the end of which the fruit was removed and examined. The pulp was found to be firm and corky. The fruit did not ripen well after removal from refrigeration.

Fruits of the green variety of star apple were picked when nearly ripe, and held at 32° F. for one month. A slight shriveling of the skin appeared after ten days. Small mold spots developed on

one fruit during the month. When removed for examination after 30 days of refrigeration, the fruits showed a slightly discolored and somewhat shriveled rind. The pulp was perfect in color and texture, and the flavor excellent. The pulp was more attractive in appearance than when picked fresh from the tree.

Small purple star apples were picked in a green condition and held at 32° F. for 58 days. In this variety as in the case of all other fruits reported on in this bulletin samples were removed for examination at weekly intervals. At the end of two weeks the flavor and appearance of the pulp were excellent. The same was true at the end of the month. One fruit showed mold on the rind and fermentation in the pulp.

Small purple star apples were picked in a half ripe condition and held for 36 days at 32° F. The skin gradually faded and shriveled after the second week. At the end of the period the pulp of the fruit was firm, of good color and perfect flavor. The same variety, picked ripe, kept well for 30 days, but at the end of a period of 57 days had deteriorated in color and appearance externally, while the pulp was still perfect in flavor.

Specimens of the same varieties of star apples, picked green, half-ripe and ripe were placed in refrigeration at a temperature of 45° F. for a period of 40 days. The same changes were observed as in fruit held at 32° F. The deterioration was somewhat more rapid, however, and molds developed more extensively on skin abrasions. The color of the skin was better preserved at 45° than at 32° F. The texture of the rind, however, and the texture and flavor of the pulp were much better in the fruit held at 32° F.

From these tests the conclusion may be drawn that star apples intended for cold storage should be picked in a half-ripe condition, cured in a well ventilated room for about two days, and then held at 32° F. for not longer than three weeks. A discoloration and fermentation of the pulp begins sooner in fruit infested with fruit fly than in uninfested fruit.

FIGS.

Figs of several common varieties were placed in cold storage at

32° and 45° F. The fruit was in the proper degree of ripeness for table use when picked. It was held for one day in the Station fruit room before going to refrigeration. After 12 days at 32° F. a few of the figs showed mold on the rind, but the mold had not penetrated the pulp. The color of the pulp was good and the flavor had suffered no change. The remainder of the fruits were in excellent condition without any signs of mold on the surface when examined after 17 days. A few mold spots appeared after 22 days. The flavor and physical condition of the pulp was still perfect at the end of a month, but after 44 days the flavor began to deteriorate and the fruit began to absorb an odor resembling ammonia. A part of the figs had been exposed to infestation with fruit flies. These fruit, held at a temperature of 32° F., kept their flavor and condition until fermentation set in about the infested areas at the end of 30 days. •

Figs held in cold storage at 45° broke down sooner than those held at 32° F. At the end of 40 days all the figs in the 45° room showed mold on the outside of the skin, and most of them had deteriorated in flavor and appearance.

On the whole figs, even when picked in a ripe condition, seem to be adapted to cold storage at 32° F. for a period of about one month. As a result of refrigeration the pulp is firmer and more attractive in appearance than when freshly picked from the tree, and the flavor is about equal to that of the freshly picked fruit.

PAPAYAS.

Papayas of six varieties were used in testing their adaptability to cold storage. They were placed in two refrigerator rooms with a temperature of 32° and 36° F. respectively. The fruit was picked in three stages, green, half-ripe and approximately ripe. Those which were nearest ripe were all yellow in color, but were still firm. After 27 days in storage, most of the papayas began to show small mold spots on the skin. These spots increased in size rather rapidly and the fermentation extended into the pulp of the fruit. Aside from the development of mold on the skin, the texture and flavor

of the fruit was perfectly preserved. There was a tendency, however, to develop a slight cold storage odor, due to the absorption of ammonia. Papaya fruits which had been punctured before going to cold storage began to ferment and decay badly within 24 hours after removal at the end of a month of refrigeration. Even the use of a formalin wash on refrigerated papayas failed to prevent the rapid development of mold on the rind after the fruit had been removed from cold storage.

The same results were obtained with the papayas which were held at 36° F. The fruit appeared to keep as well at this temperature as at 32° F. The mold did not develop very rapidly in the case just mentioned.

On account of the relatively extensive growth of mold on the rind of papayas, another test with this fruit was made in which the fruits were carefully washed in a three per cent solution of formalin and then thoroughly dried and placed in paper bags before going to cold storage. The fruit in this test was nearly ripe when picked. The use of formalin in this manner seemed to prevent the development of mold. All of the fruit was still in perfect condition at the end of one month. After 40 days the pulp was found to be ripened to about the softness which is desirable for table use. Some of the pulp was slightly watery, but no more so than occurs normally in the ripening of papaya. The flavor was good, with little or no evidence of a cold storage odor.

At a temperature of 36° F., fruits similarly treated with formalin before being sent to refrigeration kept equally well with those in the 32° F. room, except for the appearance of a few spots of mold. The preservation of the fruit was practically perfect for 45 days, at the end of which time the fruit had completely ripened with a good flavor.

Papayas seem not particularly adapted to cold storage on account of the tendency to the development of molds. The common mildews or molds grow very rapidly in the dry papaine or juice of the papaya which exudes from minute skin punctures. It is practic-

ally impossible to find a papaya fruit without skin punctures on account of the great delicacy of the skin. Even small grains of sand carried by the wind abrade the fruit. The juice exudes at once and dries and in this material molds rapidly develop. Furthermore there is little necessity for holding papayas in cold storage except for transportation, for the reason that the fruit ripens the year round.

The waterlemon (*Passiflora laurifolia*) used in this experiment was obtained from a regular shipment of the fruit which had been sent to the Territorial Market. They were of the common yellow variety, and had received no special care in transportation, being shipped loose in barrels. This fruit kept in perfect condition in both the 32° and 36° F. rooms for a period of three months. At the end of that time the appearance of the rind, the fibrous bag inside the rind, and the pulp of the fruit was the same in all respects as when the fruit was put in cold storage. The flavor underwent no alteration whatever during the whole three month period. As in the case of other fruits, samples were taken out each week for examination. Waterlemons seem to be the best adapted to cold storage preservation of all the fruits with which experiments were made. It is difficult to understand why there should be so much difference in keeping properties between the Hawaiian waterlemons and the passion fruits with which Benson experimented in Australia. The waterlemons after being kept for three months in cold storage were found to hold their flavor and physical appearance for four days after removal from refrigeration.

STRAWBERRY GUAVA.

A few fruits of the strawberry guava (*Psidium cattleianum*) were placed in cold storage in the 32° and 36° F. rooms. This fruit is one of the preferred host plants of the fruit fly, and a part of the fruit used in the experiment was infested. The fruit was picked in a nearly ripe condition. The strawberry guava is not well adapted to cold storage. Practically all of the fruit was shriveled and fermented or decayed within one month in both the 32 and 36° F.

rooms. Mildew developed abundantly on the rind and only a few of the fruits kept their normal flavor and appearance more than two weeks.

MANGOS.

The mango season in Hawaii, while a long one, could be extended to advantage by means of cold storage, particularly of the better flavored varieties. The only two varieties which we used in this experiment were Java No. 1950 and No. 1977. Boxes of both of these varieties were placed in the 32° and 36° F. rooms. The fruit in all cases was held in the station fruit room before going to refrigeration. The most of the fruit had been bagged on the trees, and was therefore not exposed to fruit fly infestation. Some of it, however, had been stung by the fruit fly. In the 32° F. room the appearance of the fruit remained normal in every way for the first month. The rind then showed slight shriveling and a deadening of the color. Fruit removed at this time were found to possess a normal pulp in perfect preservation, with good flavor and with no noticeable changes. The subsequent changes consisted in a shriveling of the skin which injured somewhat the appearance of the fruit. The pulp, however, remained in good state of preservation for a period of two months, possessing at the end of that time a normal flavor. After refrigeration for two months the fruit was removed to the station fruit room at an ordinary temperature for a period of two days. At the end of that time the flavor of the fruit was found to be slightly flat. This was more noticeable in the fruit which had been held at 36° F. than in that which was in the 32° F. room.

Mango No. 1977, some of which was picked in a perfectly ripe condition, preserved the normal texture and flavor for a period of 35 days. After that the flavor deteriorated slightly, but was by no means abnormal. The flavor of the green fruit of this variety was also perfectly preserved for a period of two months. No fermentation or other change took place in the fruit within two days after removal from cold storage.

PINEAPPLES.

Pineapples of the smooth Cayenne variety were tested for their

adaptability in cold storage in a green, ripe and half-ripe condition in the 32° and 36° F rooms. In the 32° F. room after one month, ripe pineapples showed a slight deadening of the normal yellow color. The rind otherwise was in perfect condition with the exception of a few mildew or mold spots which did not penetrate into the fruits. The flavor at the end of one month was excellent, and equal in most cases to that of the pineapple freshly cut from the plant. In a few cases the acidity seemed to be less than is normally the case, at least as judged by the taste. No chemical tests were made. After 45 days the leaves of the crown appeared to be slightly withered and minute traces of softening extended for a short distance into the pulp from two or three eyes. These phenomena appeared only in the ripe and half-ripe fruit. In the green fruit preservation was still perfect at the end of 45 days. Essentially the same results were obtained in the 36° F. room, except that the flavor of the pineapple began to deteriorate after 35 days in the case of the fruits placed in refrigeration at a ripe state. There was also a greater tendency for the development of a superficial mold which did not, however, penetrate the pulp. From these experiments the conclusion may be drawn that half-ripe and ripe pineapples may be held in cold storage at a temperature of 32° F. without harm to the color or flavor of the pulp of the fruit. The only change is a slight deadening of the color of the rind.

AVOCADOS.

With the considerable number of varieties of avocado which are now grown in Hawaii the season of this fruit has been extended to cover six months or more a year. It was desirable to know, however, whether some of the better varieties could be held for a month or more in cold storage in order to prevent the loss which occurs when the fine varieties are shipped in such quantities as to flood the market. Only a few fruits of the hard-shelled Guatamala variety of avocado were available for testing. These fruits were kept in the station fruit room one day before going to cold storage and were then held in the 32° and 45° F. rooms for a period of 65 days, being

examined in storage at weekly intervals. A few of the fruit had been picked too green and did not ripen or show any tendency to soften during the test. Those which had been picked half-ripe began to manifest an approach to table ripeness after a period of one month. At the end of two months the pulp was found to be of normal color and excellent flavor with no apparent alterations due to cold storage.

In further cold storage tests of avocados, boxes of miscellaneous varieties were used from Kona and the island of Oahu, and a few boxes of finer flavor from those bearing station numbers 1855 and 1871. In all cases the fruit preserved its normal color, appearance, texture and flavor for a period of two months in either the 32° or 36° F. room. There was in no case any discoloration of the pulp or fermentation or apparent loss of flavor. The color of the skin became slightly deadened after 75 days, but the pulp was still in perfect condition.

When removed from cold storage after a period of 60 days the fruit which had been kept in the 32° F. room held up longer than that from the 36° F. room. Avocados picked green and held in cold storage for two months ripened with good flavor within three days after removal from cold storage and held their flavor well for a period of six days. The avocado seems to be well adapted to cold storage at a temperature ranging from 32° to 36° F. for a period of at least two months.

EFFECT OF COLD STORAGE ON GERMINATION OF SEED.

Seed from several varieties of star apple were planted after the fruit had been in cold storage various lengths of time. Seed from fruit held at 45° F. for various periods up to 25 days germinated promptly to the extent of 90 per cent. Seed from fruit held for more than 30 days in cold storage failed to germinate at all. Similarly with the seed of avocados, no germination took place from fruit held longer than 20 days at a temperature of 32° F.

EFFECT OF COLD STORAGE UPON MEDITERRANEAN FRUIT FLY.

In 1907 some experiments were made in Australia* in which it was found that fruit fly maggots would resist temperatures from 44 to 38° F., but that at 33 to 35° F. eggs, after a short period of retention in cold storage, appeared fresh, but ultimately shriveled and failed to hatch after removal from cold storage. The maggots and eggs of fruit flies were found to live for 15 days at 33 to 35° F. In the beginning of the cold storage experiments reported in this bulletin some infested star apples were removed after 10 days in cold storage at 32° F., and placed in breeding jars. The maggots at the time of removal from cold storage were full grown and of normal color, but limp and apparently dead. No pupae developed, and no adult flies were recovered from this material. Similarly with figs removed after 10 days from refrigeration at 32° F., no adult flies could be bred from this material.

In order to test the effect of cold storage upon fruit flies in a more systematic manner a quantity of infested mangos and citrus fruits were picked and placed in the 32° and 36° F. rooms. Three fruits each of mangos and citrus fruit were placed in 13 baskets in each room. Each basket contained three mangos and three citrus fruits. One basket was removed from each room after an exposure of two and a half days, and one basket from each room thereafter for each day until a period of 15½ days had elapsed. The fruit upon removal from cold storage was placed in glass jars containing about 2 inches of moistened sand and covered with muslin. On the fourteenth day after removal from cold storage one adult fly emerged from the fruit which had been held 2½ days at 36° F. The next day three flies emerged from the fruit which had been held 2½ days at 32° F. Nine days later four flies emerged from the fruit which had been held 3½ days in cold storage at 36° F., and two flies from fruit which had been in cold storage 4½ days at the same temperature. Adult flies continued to emerge from the fruit which had been in cold storage 2½ days at 36° F., until in all,

* Jour. Dept. Agr. West Aust. 15 (1907) p. p. 252, 253.

30 flies appeared in that jar. Adult flies also continued to emerge from fruit which had been in cold storage $2\frac{1}{2}$ days at 32° F., until the whole number was 25. From that time on no more adult flies emerged from any of the jars. In this test therefore no adult flies emerged from fruit which had been held at a temperature of 32° F. longer than $2\frac{1}{2}$ days, and no flies emerged from fruit which had been held at a temperature of 36° F. longer than $4\frac{1}{2}$ days.

All of the fruit in these jars was badly infested and contained large numbers of eggs and of half and full grown maggots when placed in cold storage. The fruit was not cut open or otherwise disturbed after removal from cold storage, but was merely held in the breeding jars in order to determine whether any of the maggots in the fruit would be able to complete their development.

At the same time with these experiments, four small glass jars containing moist sand in the bottom in which six full grown fruit fly larva had been placed were put in each of the two refrigeration rooms. One jar was removed from each room at the end of 4, 7, 11 and 14 days.

The following results were obtained from the test in the 32° F. room. In the jar removed after 4 days, all six larva were limp and motionless but not discolored. Two larva subsequently pupated, but no further development took place. All jars were given a final examination 22 days after removal from cold storage. The jar which had been held for 4 days at 32° F. contained 2 dead pupa and 4 dead larva. In the jar which was held 7 days in cold storage all the larva were dead and showed a brownish discoloration upon removal. The same findings were made in the jars removed after 11 and 14 days. No adult fruit flies emerged from any of the jars held at a temperature of 32° F.

From the jars placed in the 36° F. room the following results were obtained. The larvae were alive and one had pupated at the end of 4 days. From jar removed after 7 days two were dead and four alive. All larvae were dead in the jars removed after 11 and 14 days. In the jar removed after 4 days one adult fly appeared

15 days after removal. This was the only fly to emerge from any of the larvae held in sand in cold storage.

Avocados are perhaps the only commercial Hawaiian fruits subject to infestation with Mediterranean fruit fly for which there is a demand on the mainland. In the experiments just reported fruit fly larva and eggs failed to live through an exposure in cold storage even at 36° F. for longer than 4½ days. It is not safe, however, to assume 4½ days as an outside limit. It would seem safe to assert that infested fruit maintained for two weeks at a temperature of 32° F. could not possibly contain the living fruit fly in any stage. Avocados, however, may be held for at least two months in cold storage.

Dr. E. A. Back and Mr. C. E. Pemberton since May, 1913, have been making elaborate experiments with fruit flies in cold storage. Their results, soon to be published, will show all the conditions of cold storage which must be observed to render infested fruit safe.

PICKLING AVOCADOS IN SALT BRINE.

It has sometimes been asserted that avocados could be pickled in salt water in such manner as to destroy the fruit fly and make them safe for shipment to the mainland. In order to determine this matter a few tests were made at the same time with the cold storage tests. Ripe and green avocados were placed in salt water of various strengths from ¼ pound to 1 pound of salt per gallon, and left to stand at an ordinary room temperature in glass jars. At the end of one month the avocados were found to be all perfectly preserved. The color, texture and appearance were the same as when the fruit was placed in the salt water. No fermentation or decay had taken place. The fruits were then placed in fresh water to extract the salt in order to determine the flavor of the fruit thus preserved. It was found that the flavor was flat and disagreeable. It seems doubtful whether avocados can be preserved in salt water without losing much of the delicacy of their flavor.