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COLD STORAGE BEHAVIOR OF AVOCADOS

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From time to time the growers and, since its organization, the California Avocado Association, have been interested in knowing something of the keeping qualities of the different varieties of avocados in cold storage. Occasionally it has appeared desirable to retain a portion of the crop of certain varieties in cold storage to delay their being placed upon the markets, in order to facilitate their disposal and in order to obtain better prices.

So far as time, facilities and availability of material permitted, the Division of Pomology at Berkeley, has attempted to conduct some preliminary investigations. Because of the expensiveness of the fruit it has been difficult to obtain sufficient quantities for experimental purposes to enable conclusive data to be obtained.

Review of Previous Work

Collins (1) in 1905 wrote that shipments of avocados, made at air temperatures, were sometimes placed in cold storage as soon as they reached New York, in order to hold the fruit for the fall trade, and that even though the loss was heavy, the increased price still made it a profitable procedure. There was, however, a very uncertain element, for with fruit that appeared uniform when placed in cold storage, some came out in sound condition while the remainder was completely decayed. Collins stated that this lack of uniformity in the keeping qualities was probably due to the different degrees of maturity at which harvested, and to conditions to which it had been subjected, although it was difficult to detect such differences from the outward appearance of the fruit.

Condit (2) in 1915 mentioned that experiments with cold storage for avocados show that the fruit can be held at a temperature ranging from 32 degrees to 35 degrees F. for a period of at least two months.

Dybowski (3) in 1902 stated that shipments of avocados have been made in cold storage from the Antilles to France, and that a temperature of 2 degrees C. (35-5 degrees F.) was found most satisfactory. He recommended that the fruit be wrapped in paper and packed in excelsior. Shipments made in this way were said to reach France in good condition.

Higgins (4) in 1904 reported a shipment of avocados from the Hawaiian Islands to New York City with encouraging results. These preliminary experiments, according to Higgins, indicated the advisability of quickly placing the fruits in cold storage as soon as possible after gathering. Fruits were also kept in the ice house in Honolulu, but according to Higgins, after being retained for many weeks, the first signs of deterioration

were manifest in a darkened color of the flesh and loss of flavor, though the fruit remained solid.

Higgins, Hunn and Holt (5) of the Hawaiian Islands in 1911 stated that it was of great importance that refrigeration be begun as soon as possible after picking, since it was difficult to arrest the ripening process of avocados when it had progressed far. Their experiments showed that prolonged storage temperatures of 32 degrees to 35 degrees F. such as used for deciduous fruit, resulted in the blackening of the interior of the avocado although such temperatures could apparently be endured without injury for about three or four weeks. They recommended that the temperature should not be permitted to fall below 40 degrees F.

Wilsox (6) as Special Agent in charge of the Hawaii Agricultural Experiment Station in 1914, reported that holding fruit infested with the fruit fly for a period of ten days at a temperature of 32 degrees F. destroyed the fruit fly in whatever stage it may be present. He wrote that it had been demonstrated that avocados may be held without injury to the fruit at a temperature of 32 degrees F. for at least two months.

Points Investigated

The points investigated by the Division of Pomology included the following:

1. An attempt was made to determine the most satisfactory temperature. The temperatures employed in the study were as follows: (a) 10 degrees 12 degrees F; (b) 32 degrees F; (c) 36 degrees F; (d) 40 degrees F; (f) 45 degrees F; and (g) room temperatures, 65 degrees to 75 degrees F.

2. The storage periods determined were: (a) the *optimum storage* or the latest time of removal from storage, which would give the best results regarding the quality, appearance, and time of holding up after removal from storage. (b) The *maximum storage,* or the time beyond which at a given temperature it would be unsafe to keep the fruit in storage,-—even though it might still appear to be in good condition,—because of the loss of quality, softening of the texture, discoloration of the flesh, susceptibility to rot organisms, tendency to wilting and rapidity of breakdown after removal.

3. The relative keeping quality of the more important varieties insofar as they were available.

4. The effect of maturity at the time of harvest upon the subsequent flavor developed.

5. The freezing temperature of avocados.

6. Observations of storage fungi, bacterial and physiological diseases of avocados.

Method of Procedure

The avocados were furnished by various growers, or the California Avocado Association, and were shipped by express to the Division of Pomology at Berkeley.

The fruits were placed under the various conditions hereinafter described and observations were made at sufficiently frequent intervals.

Presentation of Data

The work reported herewith was conducted during the seasons of 1920 to 1922 inclusive, and during 1924-25. The observations of each season are reported separately.

Season of 1920. In 1920 W. A. Spinks furnished the Spinks avocado; E. E. Knight, the Kist and Rey; and the San Joaquin Fruit Company the Fuerte, Challenge and Royal. All the fruit was received in a hard, unripe condition. The Fuerte, Challenge, Spinks and Royal were stored at temperatures of 32 degrees, 36 degrees and 45 degrees F; the Kist and Rey were stored at 36 degrees and 45 degrees F. and together with the Spinks were also observed at room temperatures. The observations with the Challenge and the Fuerte in 1920 indicated that a temperature of 32 degrees F. was unfavorable for the storage of these varieties, as the flesh or pulp browned, rotted or wilted and the skin or epidermis became scalded and shriveled. The Fuerte especially proved to be susceptible to wilting and scald. At this temperature the fruit tended to remain firm for a relatively long period of time, but when finally removed to room temperatures satisfactory ripening did not follow. Instead the fruit remained hard, but became dry and browned or blackened.

The Spinks variety withstood the temperature of 32 degrees F. somewhat better than did the Fuerte and the Challenge, but the period of time that the Spinks remained marketable when stored at 32 degrees F. was less than when stored at 36 degrees F.

The Royal, however, appeared able to withstand the temperature of 32 degrees F. and could be kept longer at 32 degrees F. than at the other temperatures, having a maximum storage period of about two months, and upon removal subsequently ripened satisfactorily.

All the varieties tended to remain firm at 32 degrees F. and the problem with the Royal was to avoid permitting it to remain too long at 32 degrees F. so that when again removed to room temperature it would not properly ripen and attain good quality.

The behavior at 36 degrees F. with all of the varieties except the Royal was better than at 32 degrees F. Whereas at 32 degrees F. the fruit did not soften, at 36 degrees F. the texture gradually became soft and thus gave evidence of ripening progress so that it was possible to estimate more satisfactorily the optimum and maximum storage periods. Nevertheless, at 36 degrees F. there was also the tendency for the fruit to remain sufficiently firm that the possibility prevailed of permitting the fruit to stay in storage too long and hence when finally removed to room temperature it would wilt, become blackened and fail to ripen.

At 45 degrees F. the fruit of all the varieties ripened and softened in a manner so that it could be determined approximately when the proper time for removal had arrived.

At all of the temperatures the Royal proved to be the best keeper, the Spinks and Challenge next, with the Fuerte, Kist and Rey following in about the order named. The data are summarised in table 1.

TABLE 1

The Behavior of Avocados in Storage duging the Season of 1920

Variety	Date Picked 1920	Date Stored 1920	Temp. of Storage	Days to Optimum Storage	Days to Maximum Storage
Spinks	4-15	4-17	70 Deg. F.	9	12
Kist	6-9	6-11	70 Deg. F.	10	13
Rey	6-9	6-11	70 Deg. F.	10	14
Kist	6-9	6-11	45 Deg. F.	17	20
Fuerte	3-7	3-9	45 Deg. F.	15–18	19–22
Challenge	3-7	3-9	45 Deg. F.	19	28
Spinks	4-15	4-17	45 Deg. F.	22	30
Rey	6-9	6-11	45 Deg. F.	17	20
Royal	3-7	3-9	45 Deg. F.	33–37	38–43
Kist	6-9	6-11	36 Deg. F.	19	26
Fuerte	3-7	3-9	36 Deg. F.	25	30
Rey	6-9	6-11	36 Deg. F.	24	31
Challenge	3-7	3-9	36 Deg. F.	30	40
Spinks	4-15	4-17	36 Deg. F.	32	45
Royal	3-7	3-9	36 Deg. F.	45	55
Fuerte[1]	3-7	3-9	32 Deg. F.	----	----
Challenge[1]	3-7	3-9	32 Deg. F.	----	----
Spinks	4-15	4-17	32 Deg. F.	30	35
Royal	3-7	3-9	32 Deg. F.	50	60

[1]Failed to ripen at 32 degrees F.

Season *of 1921-22.* Work was conducted during the season of 1921-22 with the following varieties: Fuerte, Spinks, Dickinson, Queen and Sharpless. The data obtained are summarized in table 2.

TABLE 2

The Behavior of Avocados in Storage During Season of 1921-22

Variety	Date Picked 1921	Date Stored 1921	Temp. Stored	Period of Optimum Storage	Period of Maximum Storage
			Room		
Fuerte	3-16	3-19	66 Deg. F.	5-8 days	11 days
			Room		
Spinks	4-28	5-2	66 Deg. F.	7 days	12 days
			Room		
Dickinson	7-4		66 Deg. F.	7 days	12 days
			Room		
Sharpless	11-22	11-25	66 Deg. F.	9 days	13 days
			Room		
Queen	7-8	7-11	66 Deg. F.	9 days	18 days
Dickinson	7-4	7-7	45 Deg. F.	10 days	17 days
Fuerte	3-16	3-19	45 Deg. F.	16 days	23 days
Spinks	4-28	5-2	45 Deg. F.	22 days	29 days
Sharpless	11-22	11-25	45 Deg. F.	26 days	31 days
Queen	7-8	7-11	45 Deg. F.	30 days	39 days
Fuerte	3-16	3-19	40 Deg. F.	Flesh discolored.	
*Spinks	4-28	5-2	40 Deg. F.	22 days	29 days
†Spinks	4-28	5-1	40 Deg. F.	44 days	54 days
Sharpless	11-22	11-25	40 Deg. F.	34 days	41 days
†Sharpless	11-22	11-25	40 Deg. F.	Flesh discolored.	
Queen	7-8	7-11	40 Deg. F.	44 days	54 days
†Queen	7-8	7-11	40 Deg. F.	Fruits failed without ripening properly.	
Dickinson	7-4	7-7	40 Deg. F.	58 days	68 days
†Dickinson	7-4	7-7	40 Deg. F.	Flesh discolored.	
Fuerte	3-16	3-19	36 Deg. F.	Flesh discolored and epidermis scalded.	
Spinks	4-28	5-2	36 Deg. F.	Flesh discolored.	
Sharpless	11-22	11-25	36 Deg. F.	Flesh discolored.	
Queen	7-8	7-11	36 Deg. F.	One fruit kept 44 days ripened satisfactorily.	
Dickinson	7-4	7-7	36 Deg. F.	One fruit kept 48 days ripened satisfactorily.	
Fuerte	3-16	3-19	36 Deg. F.	Flesh discolored and epidermis scalded	
Dickinson	7-4	7-7	32 Deg. F.	Fruits discolored.	
Queen	7-8	7-11	32 Deg. F.	Fruits did not ripen properly.	
Spinks	4-28	5-2	32 Deg. F.	1 fruit stored 22 days ripened satisfactorily.	

*Due to fruit being almost ripe upon arrival.
†The stem ends of these were coated over with paraffin.

The Behavior of the Fuerte. After five days storage at 32 degrees F. the fruit of the Fuerte showed severe scald whereby the natural green color of the epidermis turned brown. Otherwise they were in excellent condition. Later on, however, when successive removals were made, the pulp was found to be brown and hard, apparently changing color without ripening; Scalding and similar behavior also resulted in the 36 degrees F.

temperature after seven days storage.

Fruits kept at 40 degrees F. showed no scalding, and judging by the appearance of the epidermis, apparently kept in excellent condition. However, when permitted to remain at this temperature, the pulp became badly browned and remained in a firm unripened condition. The work of the two seasons indicated, therefore, that for the Fuerte, temperatures of 40 degrees F. and below were unsatisfactory for storage because of the possibility of the browning of the epidermis and flesh. At 45 degrees F. the fruits ripened and became sufficiently soft to indicate the approximate desirable time of removal from storage. The Fuerte kept satisfactorily at 45 degrees F. for about three weeks. At room temperatures of 65-70 degrees F., the Fuerte kept only 11 days.

The Spinks, Dickinson, Queen and Sharpless showed no scald at any of the temperatures in contrast to the thinner skinned Fuerte. They did, however, show browning of the flesh at the lower temperatures.

Difficulty was experienced with the Dickinson, due to its thick, hard skin, in ascertaining when it was ripe, in that it did not soften characteristically as did the others.

Some of the fruits were wrapped in oil wrappers, but this appeared to hasten the time when the flesh became black. Coating of the stems and stem ends of the fruits with paraffine seemed in most cases to prolong the storage period of the avocado considerably and lessened the tendency for the flesh to become blackened.

Season of 1924-25. During the 1924-25 season the California Avocado Growers Exchange sent specimens of the Taft and Spinks avocados to be used by the Division of Pomology in the study of their behavior in cold storage. The observations are summarised in tables 3 to 5.

Storage temperatures.—The data in table 3 indicate that with the Taft and Spinks varieties the most satisfactory storage temperature was 40 degrees F. Not only did the fruit keep a longer period of time at this temperature, but the quality was superior to that attained by the fruit at the other cold storage temperatures. The quality attained by the fruit at 32 degrees F., was especially inferior, the flesh becoming somewhat tough and stringy. At 45 degrees F. the fruit ripened more quickly and the flesh became more rancid than at 40 degrees F.

At all of the temperatures the flesh tended to become darkened but this tendency was more marked at 32 degrees F. than at 40 degrees F. The Taft kept better at all of the temperatures than did the Spinks.

Mold and rot organisms attacked the fruits at temperatures of 40 degrees F. and above. Very little mold was noticed on the fruit stored at 32 degrees F. Rot and mold were more severe when the stem had been removed from the fruit in handling previous to storage. The basal end of the fruit, however, proved susceptible to mold even with the stem present. Bruises and abrasions of the epidermis likewise afforded an opportunity for the molds to become established. The importance of careful handling of fruit to be stored was emphasized.

TABLE 3

The Effect of Storage Temperature Upon Keeping Quality of Avocados (1924)

Variety	Average Date Stored	Storage Temperature	Days kept to Maximum Storage
		Room Temp.	
Taft	July 4	65-75 Deg. F.	6
Spinks	June 9	65-75 Deg. F.	5
Taft	July 4	45 Deg. F.	39
Spinks	June 9	45 Deg. F.	29
Taft	July 4	40 Deg. F.	56
Spinks	June 9	40 Deg. F.	42
Taft	July 4	32 Deg. F.	43
Spinks	June 9	32 Deg. F.	36

Degree of maturity.—The data in table 4, indicate that with the Taft the fruit kept better and possessed a higher eating quality when picked just prior to the period when the fruit showed signs of softening. The more immature fruit was lower in quality and often became fibrous, stringy and wilted in texture. The fruit which had begun to soften attained good quality but did not keep as long as the more properly mature fruits. At 40 degrees F., the Taft when received in a firm unripe to firm ripe condition, kept 65 days; in a ripe condition with slight softening, 47 days; and in a hard unripe condition, 40 days.

Apparently at all the storage temperatures the tendency for the skin to darken depended principally upon the degree of maturity at the time of storage. The greater the degree of maturity, the more the tendency for the darkening to occur. The darkening was retarded more by storage at the temperature of 40 degrees F. than at the other temperatures.

TABLE 4

The Effect of Degree of Maturity When Harvested Upon the Keeping Quality of the Taft. (1924)

Date Stored	Maturity when Stored	Storage Temperature	Days kept to Maximum Storage
June 2	Hard unripe.	40 Deg.F.	40
July 12	Firm unripe to firm ripe.	40 Deg. F.	65
July 12	Ripe just softening.	40 Deg. F.	47
July 12	Firm unripe to firm ripe.	45 Deg. F.	44
July 12	Ripe just softening.	45 Deg. F.	29

The ripest specimens showed signs of dark spotting of the skin when they were received. Further coloration of the flesh was more rapid at temperatures of 45 degrees F. and above.

Delay in Storing.—The undesirable effect in shortening the subsequent storage period of any delay in storing was quite marked. The data in table 5 show that specimens of the Taft stored at once upon receipt at 40 degrees F. kept 56 days. When they were held at room temperatures (65-75 degrees F.) for 5 days previous to storage at 40 degrees F. they kept only 37 days longer or a total of 42 days. When the delay was 8 days they kept only 7 days longer at 40 degrees F. or a total of 15 days. The necessity of immediate placing in cold storage with minimum delay was emphasized.

TABLE 5

The Effect of Delay in Storing Upon Subsequent Keeping Quality

(Taft, 1924)

Days Delay Before Storing	Temperature of Storage	Days kept to Maximum Storage
None	40 Deg. F.	56
5	40 Deg. F.	37
8	40 Deg. F.	7

Average of Three Seasons.—The average keeping quality at the optimum temperature for each of the varieties as determined by the tests reported is shown in table 6.

TABLE 6

The Average Keeping uality of Avocados at Their Optimum Storage Temperature

Variety	Aver. Date Stored	Year	Storage Temp.	Period of Maximum Storage
Dickinson	July 4	1921	40 Deg. F.	68 days
Royal	March 7	1920	32 Deg. F.	60 days
Taft	July 4	1924	40 Deg. F.	56 days
Queen	July 8	1921	40 Deg. F.	54 days
Spinks	May 19	1920, 21, 24	40 Deg. F.	47 days
Sharpless	Nov. 22	1921	40 Deg. F.	41 days
Challenge	March 7	1920	36 Deg. F.	40 days
Rey	June 9	1920	36 Deg. F.	31 days
Fuerte	March 11	1920, 21	45 Deg. F.	30 days
Kist	June 9	1920	36 Deg. F.	26 days

These data indicate that of the varieties studied the Dickinson, Royal, Taft and Queen were the best keeping sorts, and that the Rey, Fuerte and Kist were least satisfactory. The first four were retained in storage for approximately two months; the last three for about one month. The Spinks, Sharpless, and Challenge were intermediate in keeping quality and were retained for from five to six weeks.

The temperature which appeared to be satisfactory for the storage of most varieties was 40 degrees F. The Fuerte was an exception in that at temperatures below 45 degrees F. the fruit scalded and did not ripen properly. On the other hand the Royal kept best and longest at 32 degrees F.

Of the temperatures tested, 36 degrees F. appeared best for the Challenge, Rey and Kist, although they kept relatively short periods of time at that temperature and likewise with these varieties a temperature of 40 degrees F. was not employed.

The data for the three seasons reported cannot be said to be conclusive for the following reasons:

1. The limited number of fruits available for the experiment made the probability of error for the observations during each season quite large.

2. The variability and degree of ripeness when only two or three specimens are used

under each condition results in a greater amount of error.

3. The small number of specimens prevented also the removal of a requisite number of each specimen in the sampling, and decreased to a greater degree than desirable the frequency for which tests in quality and ripeness should be made and made it necessary to estimate by appearances rather than by actual examination such as would be afforded by cutting and tasting the fruits.

4. The work up to the present, however, should serve during any subsequent season when sufficient fruits can be supplied for study, as a good basis for the determination of data that would be accurate.

Freezing Point of Avocados.—Upon February 23, 1925, two specimens each of the following varieties of avocados were sent to the Division of Pomology for study in connection with the freezing point of the fruit: (a) Fuerte (fully mature); (b) Challenge (partially mature); (c) Pueblas (fully mature); (d) Solano (partially mature); (e) Butternut (fully mature); and (f) Butternut (immature).

The fruits were placed one at a time in a freezing chamber chilled by ammonia coils and kept at an average temperature of about 16 degrees F. The temperature fall and the freezing point were determined by means of thermo' couples and a potentiometer calibrated in degrees Fahrenheit, readings being taken at ten minute intervals.

The freezing point upon receipt of the mature specimens averaged 28.86 degrees F.; that of immature and partially mature averaged 29.06 degrees F.; the average of all varieties being 28.96 degrees F.

Specimens of the Solano and Challenge were kept in the 45 degree F. room from February 23 to April 23, or a period of about two months, until the specimens were soft ripe and then the freezing point was determined by the use of electrical resistance thermometers. The average freezing point of the two varieties was 28.35 degrees F. The average freezing point of similar mature specimens upon arrival was 28.80 degrees F., indicating that as ripening progressed after harvest the freezing point became further depressed.

Subsequent to thawing following freezing the skin and stem became blackened. While the flesh remained normal in appearance for a time the fibro' vascular strands darkened. The flesh darkened, however, within several hours. The flavor of the frozen fruits was excellent and the tissue was pleasing to eat while frozen. Upon thawing, however, the flavor was impaired and the texture became objectionably soft.

Specimens were kept frozen, up until the time of the preparation of this paper, or about two months, and were still pleasing to eat with a distinct rich "nutty" flavor in the frozen condition. Upon thawing, however, both the texture and flavor were found to be impaired and the exposed surfaces became blackened in color.

The stem tissue showed injury at slightly higher temperatures than the fruit. The skin, especially of the green colored fruits evidenced injury at slightly lower temperatures than did the stem and the fibra-vascular strands at still somewhat lower temperatures. The pulp was the last tissue to show injury. No observations were made upon the seeds.

Summary

1. The data indicated that temperatures of 32 degrees F. were too low for the successful cold storage of most varieties of avocados.

2. At these low temperatures, the skin tended to exhibit a scalded appearance, the flesh remained firm but turned brown and upon removal the fruit subsequently failed to ripen and soften properly.

3. One year's observation indicated, however, that the Royal may be an exception, in that under certain conditions it may be kept satisfactory at 32 degrees F.

4. Most of the other varieties kept best at a temperature of 40 degrees F., the fruit ripening satisfactorily in storage or subsequent to removal and attaining good quality. Likewise 40 degrees F. sufficiently retarded ripening to prolong appreciably the marketing period.

5. The Fuerte proved to be an exception in that at temperatures below 45 degrees F. the normally green skin tended to blacken.

6. The necessity of quickly placing in storage after harvest and the need of care in handling to avoid bruising the fruit or dislodging the stem was emphasised.

7. Proper stages of maturity for harvesting fruit to be stored is difficult to define, but fruit picked just prior to evidence of softening of the texture kept best and attained excellent quality. Immature fruit became fibrous and stringy in texture, wilted and possessed inferior quality. Fruit too advanced in maturity did not keep as well in storage but attained good quality.

8. When properly stored the Dickinson, Royal, Taft and Queen were kept for about two months; the Spinks, Sharpless and Challenge for from five to six weeks and the Rey, Fuerte and Kist about four weeks.

9. The freezing point shortly after harvest of fairly mature avocados was found to be about 28.86 degrees F.; for immature and partially mature specimens about 29.06 degrees F. For well ripened soft specimens that had been stored at 45 degrees F. for two months the freezing point was approximately 28.35 degrees F.

10. The flavor of frozen avocados was excellent, but after thawing the flavor was unsatisfactory, the *texture* soft, and the skin and flesh blackened.

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