Circular No. 600

May 1941 • Washington, D. C.

UNITED STATES DEPARTMENT OF AGRICULTURE

Mortality of the Apple Maggot in Fruit Held in Cold Storage

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INTRODUCTION

In recent years the sanitary requirements of a number of foreign countries have made it necessary to limit exportation of apples from the United States to fruit found free of infestation by the apple maggot (*Rhagoletis pomonella* (Walsh)). This species is indigenous to the Northeastern States and southeastern Canada, where it normally occurs in many unsprayed or inadequately sprayed orchards.

The apple maggot may be controlled satisfactorily, according to domestic standards, through the use of certain stomach-poison insecticides applied to the apple trees in sprays or dusts.[1] Such treatment may fall short, however, of providing the 100-percent efficiency required to meet the export standard. A situation has thus been created whereby an otherwise acceptable product is excluded from certain foreign markets on account of the presence of an occasional live apple maggot egg or larva. As it would be impracticable, if not impossible, to sort out all the infested fruits, owing to the extreme inconspicuousness of external signs of infestation, there has seemed to be a need for the development of a means of destroying the eggs and larvae in situ.

[1] Chapman, P. J., and Hammer, O. H. A study of apple maggot control measures. N. Y. State Agr. Expt. Sta. Bul. 644, 40 pp., illus. 1934.

This circular describes some of the possibilities of using cold storage for this purpose.

The senior author[2] has already presented evidence showing that all apple maggot eggs and larvae will be killed within slightly more than 30 days when infested fruit is held in an air temperature of 32° F. The two main objectives in the investigation reported here were (1) to determine, more precisely, how many days' exposure at 32° are required to effect complete mortality and (2) to determine the efficiency of higher temperatures, namely, 36° and 40°.

MATERIALS AND PROCEDURE

All the fruit used in the present study was of the Fameuse variety. The test fruit came from 5 orchards, which varied greatly in degree of infestation. Some lots averaged only 2 or 3 egg punctures per apple, whereas others averaged 30 or more, extremes for individual fruits ranging between 1 and 89 egg punctures. There were similar wide differences among the lots in the stages of the insect present and in the degree of fruit maturity. Classes under the latter category included windfalls, ripe picked fruit, and slightly green picked fruit. With respect to the insect stages, the length of time required for emergence of most of the larvae in the controls (fig. 4) indicates that the pest was present largely in the first and second instars. Some lots, however, contained unhatched eggs and others—windfall fruit especially—included third instars.

The use of such diverse material has the advantage of giving results representative of any class of fruit that might be submitted for disinfestation. This experimental advantage, however, is contingent upon the assembly of a homogeneous series of experimental units. That this objective was gained in the present instance is shown by the uniformity of the average number of egg punctures per fruit of the various lots (table 1).

Each experimental unit of fruit was put in a standard unlined bushel tub basket. The apples were not wrapped. In the refrigeration room these baskets were arranged in a group 2 feet or more above the floor. When a lot was removed from storage, each fruit was examined under magnification to obtain a record of the infestation as indicated by the egg punctures present. The lot was then placed in larval rearing equipment of the type illustrated in an earlier report[2] and held at temperatures ranging between 65° and 80° F. for a time sufficient to allow any larvae present to complete development and emerge. Some fruit was also kept in this equipment in each of the storage rooms to ascertain whether or not emergence might occur at the temperatures maintained.

Experimental lots were placed in refrigeration rooms held at air temperatures of approximately 32°, 36°, and 40° F. The cooling unit in each case consisted of brine coils located at the ceiling, and air movement was limited to that induced by gravity. A continuous record of the air temperature in these rooms was taken by means of recording thermographs installed centrally among the baskets. In general, temperature fluctuations were minor, as is indicated by the mean temperatures given for each treated lot in table 1. These are averages of hourly readings as recorded on the thermograph charts.

[2] CHAPMAN, PAUL J. VIABILITY OF EGGS AND LARVAE OF THE APPLE MAGGOT (RHAGOLETIS POMONELLA WALSH) AT 32° F. N. Y. State Agr. Expt. Sta. Tech. Bul. 206, 19 pp., illus. 1933.

EQUALIZATION OF FRUIT AND AIR TEMPERATURES

It is well known that the time required to lower the initial temperature of the fruit to the point where it is nearly as low as that of the air in the refrigeration room is a variable. Lloyd and Decker,[3] among

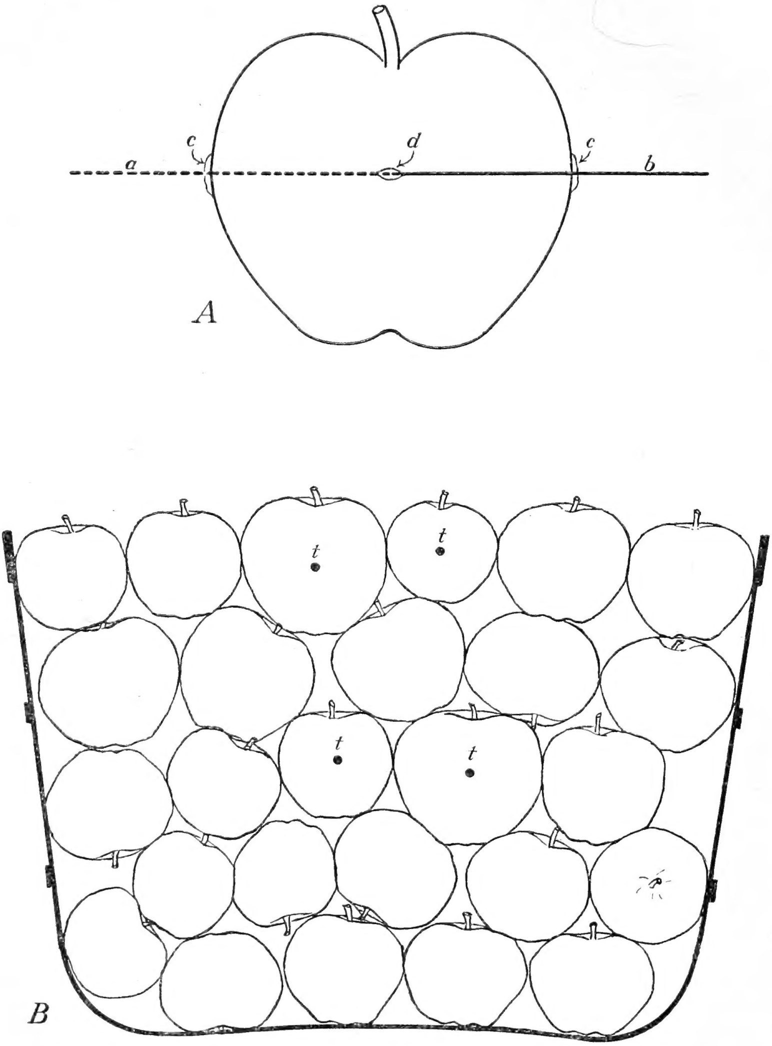

FIGURE 1.—Diagram showing position of thermocouples in fruit: *A*, Single fruit with thermocouple inserted, showing constantan wire (*a*), copper wire (*b*), paraffin to seal the wires in the fruit (*c*), and junction of the two wires (*d*). *B*, Basket of fruit showing location of thermocouples (*t*).

others, have shown this to be influenced by such factors as the velocity of air movement in the chamber, the type of fruit container, the location of any given fruit in the container, and the presence or absence of paper as lining or compartments in the container or as wrapping for

[3] LLOYD, J. W., AND DECKER, S. W. FACTORS INFLUENCING THE REFRIGERATION OF PACKAGES OF APPLES. Ill. Agr. Expt. Sta. Bul. 410, 50 pp., Illus. 1934

the individual fruits. This subject has a bearing on the problem under consideration, as it is necessary to have a common starting point in designating the time required to effect complete disinfestation.

Thermocouples were employed to determine the rate of cooling under the conditions of the present experiment. The only departure from the conventional set-up was the manner in which the constantan and copper wires were joined and placed in the fruit. To provide a known junction point, the wires were soldered together at the tip ends instead of being twisted, as is customary. Then by threading either the copper or constantan portion in a needle, it was possible to pierce the fruit readily and bring the junction at or very near the center of the fruit. No. 30-B. and S.-gage constantan and No. 32-gage copper were used. Diagrams of the set-up are given in figure 1.

The rate of fruit cooling in an air temperature of 36° F. is shown in figure 2. Almost identical curves were obtained at 32°. As pointed out by Rose, Wright, and Whiteman,[4] "although it is known to be

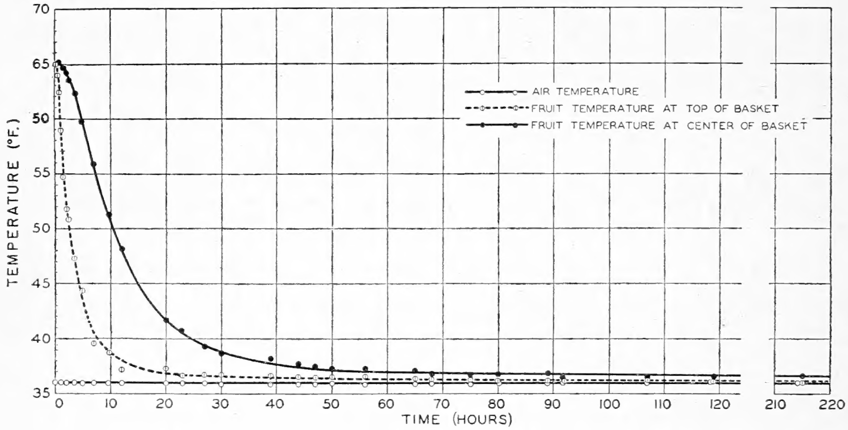

FIGURE 2.—Rate of fruit cooling in an air temperature of 36° F.

only approximately correct, * * * the rate of temperature drop at any given time during cooling is proportional to the difference between room temperature and fruit temperature at that time." The data in figure 2 show that, whereas the apples at the top of the basket appeared to cool to air temperature eventually, those at the center were still about 0.7° above after 215 hours. In the present case this difference in temperature is attributed to heat of respiration[4] [5]. Rose and coworkers calculated the amount of thermal energy produced in respiration by apples at 32° as ranging between 660 and 880 B. t. u. per ton of fruit in 24 hours. In gravity air-circulation systems the heat generated by the fruit is apparently not removed at a sufficiently rapid rate to allow the fruit in the interior of the package to attain air temperatures. In view of this situation, if the starting point in disinfestation schedules is to be based on the temperature of the fruit, it may be desirable to indicate a temperature slightly above air tempera-

[4] ROSE, DEAN H., WRIGHT, R. C., AND WHITEMAN, T. M. THE COMMERCIAL STORAGE OF FRUITS, VEGETABLES, AND FLORISTS' STOCKS. U. S. Dept. Agr. Cir. 278, 40 pp. 1933.

[5] GRIFFITHS, EZER, AND AWBERY, J. H. THE HEAT GENERATED BY FRUIT. [Gt. Brit.] Food Invest. Bd Rpt. 1927: 88–90, illus. 1927.

ture. A satisfactory base should be the time when the temperature of fruit in this position comes within 1° of the air temperature. In these experiments fruit at the center of the basket reached this temperature within about 72 hours.

Refrigeration engineers recognize that there may be some difference in temperature between the exterior and interior of a package under storage. This variation, however, can be practically eliminated through forced circulation of the air. Similarly, there is normally some variation in temperature between packages in different parts of the storage chamber. Under commercial conditions a storage temperature of 32° F. usually is understood to carry a 2° differential, or a temperature ranging from 31° to 33°. Most cold storages can operate on a 1° differential by creating sufficient air movement in the chamber and by careful regulation of refrigeration.[6]

Since in the present experiment the fruit temperature varied nearly 1° F. between the exterior and interior of the package, the fruit temperatures maintained were actually 32° to 33°, 36° to 37°, and 40° to 41°, instead of 32°, 36°, and 40°. For the sake of simplicity, however, the temperatures mentioned will refer to the approximate temperature of the air in the refrigeration room unless specifically indicated otherwise.

EXPERIMENTAL RESULTS

Detailed data on the individual experimental lots and the results obtained with fruit held at the three storage temperatures are given in table 1. The mortality for a given lot was obtained from the number

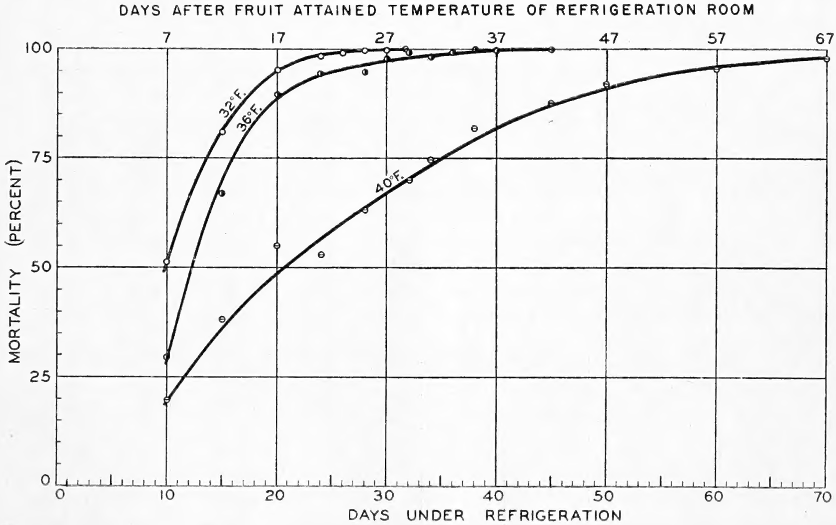

FIGURE 3.—Mortality of the apple maggot after being held for various periods in the refrigeration room at air temperatures of 32°, 36°, and 40° F.

of larvae that emerged and the number that theoretically should have emerged. This theoretical larval expectation is calculated from the ratio of the total number of larvae emerging to the total number of

[6] The generalizations appearing in this paragraph are based on statements occurring in a memorandum prepared by Lon A. Hawkins, Bureau of Entomology and Plant Quarantine, U. S. Department of Agriculture, dated April 20, 1938.

egg punctures in the controls. The relation of mortality to days under refrigeration is shown graphically in figure 3.

TESTS AT 32° F.

The results reported herein corroborate previous findings[7] that complete mortality of apple maggot eggs and larvae is effected at 32° F.

TABLE 1.—*Experimental data on mortality of the apple maggot in fruit held at various air temperatures, 1936*

Series and mean recorded air temperature (° F.)	Days under refrigeration	Total fruit	Total egg punctures	Average egg punctures per fruit	Larvae emerging		Mortality
					Actual	Theoretical	
Control series:	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Percent*
65–80	0	225	4, 034	17. 93	909	909	0
	0	248	4, 474	18. 04	1, 042	1, 042	0
Total or average		473	8, 508	17. 98	1, 951	1, 951	
32° F. series:							
32.69	10	234	4, 249	18. 16	452	974	53. 6
32.31	15	244	4, 213	17. 27	176	966	81. 8
32.32	20	240	5, 261	21. 92	49	1, 206	95. 9
32.05	24	242	4, 802	19, 84	16	1, 101	98. 5
32.17	26	234	4, 366	18. 66	7	1, 001	99. 3
32.18	28	234	3, 765	16. 09	1	863	99. 9
32.05	30	226	3, 489	15. 44	2	800	99. 7
31.99	32	236	4, 101	17. 38	0	940	100. 0
31.99	[1] 32	344	6, 226	18. 10	0	1, 428	100. 0
31.96	34	238	4, 276	17. 97	0	980	100. 0
31.96	36	237	4, 421	18. 65	0	1, 013	100. 0
31.94	38	240	3, 853	16. 05	0	883	100. 0
31.84	40	246	4, 578	18. 61	0	1, 050	100. 0
31.86	45	227	4, 409	19. 42	0	1, 011	100. 0
Total or average		3, 422	62, 009	18. 11		14, 216	
36° F. series:							
36.21	10	244	4, 253	17. 43	689	975	29. 3
35.79	15	233	4, 394	18. 86	332	1, 008	67. 1
36.33	20	246	4, 989	20. 28	112	1, 144	90. 2
36.35	24	231	4, 195	18. 16	55	962	94. 3
36.05	28	264	4, 493	17. 02	55	1, 030	94. 7
36.21	30	240	4, 251	17. 71	14	975	98. 6
36.21	32	242	4, 379	18. 09	8	1, 004	99. 2
36.07	34	249	4, 063	16. 32	19	932	98. 0
36.07	36	223	4, 326	19. 40	2	992	99. 8
36.12	38	251	3, 781	15. 06	0	867	100. 0
36.11	40	247	4, 780	19. 35	1	1, 096	99. 9
36.67	45	250	4, 418	17. 67	0	1, 013	100. 0
36.47	50	120	2, 659	22. 16	0	610	100. 0
36.44	60	126	2, 220	17. 62	0	509	100. 0
Total or average		3, 166	57, 201	18. 22		13, 117	
40° F. series:							
40.09	10	260	5, 026	19. 33	867	1, 152	24. 7
40.09	15	230	4, 392	19. 10	625	1, 007	37. 9
40.10	20	271	5, 569	20. 55	572	1, 277	55. 2
40.08	24	239	4, 568	19. 11	494	1, 047	52. 8
40.14	28	254	4, 748	18. 69	400	1, 089	63. 3
40.13	30	250	4, 022	16. 09	361	922	60. 8
40.12	32	253	4, 626	18. 28	317	1, 061	70. 1
40.15	34	241	4, 108	17. 04	233	942	75. 3
40.05	38	207	3, 978	19. 22	158	912	82. 7
40.35	45	237	4, 717	19. 90	139	1, 082	87. 2
40.36	50	231	4, 777	20. 68	88	1, 095	92. 0
40.33	60	222	4, 321	19. 46	55	991	94. 5
40.34	70	191	3, 338	17. 48	11	765	98. 6
Total or average		3, 086	58, 190	18. 84		13, 342	
Grand total		10, 147	185, 908			42, 626	
Grand average		236	4, 323	18. 36		991	

[1] Special lot, all windfalls; many fruits showed emergence holes.

[7] See footnote 2.

within slightly more than 30 days and seem to fix the storage period at 32 days. All eggs and larvae are killed within 29 days after the temperature of the fruit in the center of the package comes within 1° of the air temperature, or 33° in an air temperature of 32°.

In commercial cold storages 40 days should provide ample time for such equalization of fruit and air temperatures under various conditions and allow an adequate safety margin. The temperature maintained should not exceed 33° F. if 32° is the approximate temperature indicated for a disinfestation schedule.

No pupae were found in the fruit of this series in examinations made after larval emergence was completed. Similar results were obtained in earlier experiments.[7]

As the temperature of the fruit approaches 32°, larval progress through the flesh, as well as feeding, apparently stops, and the larvae and eggs then enter a condition which may be termed "forced dormancy." That larval activity and development cease is indicated by the fact that fruit held 10 days at 32° showed essentially the same duration and rate of emergence after removal from storage as did the control lot (fig. 4, *A*). There presumably was no marked difference in susceptibility between insect stages. Disproportionate mortality in any one stage would have modified the proportion of the several stages among the survivors, which in turn would have affected the periods when the maggots matured and left the fruit. When only a few larvae survived (lots held 24, 26, 28, and 30 days, table 1), they emerged after the fruit had been removed from storage, at a time corresponding to the median or peak emergence period in the controls. If there is a difference in susceptibility, the most resistant forms seem to be the first and second instars.

Examination of fruit at the time it was removed from storage showed that the larvae were dead, and not merely enfeebled or otherwise rendered incapable of emerging.

Tests at 36° F.

The previous statements regarding the results obtained at 32° F. apply to the findings in the 36° series, except that a longer storage period was required to effect complete mortality (table 1). This period was 45 days, or 42 days after the fruit in the center of the package came to 37°. A temperature of 36° is probably near the upper limit of temperatures that will inactivate *Rhagoletis pomonella* larvae.

Tests at 40° F.

The response of the apple maggot to a temperature of 40° F. clearly differed from that noted at 32° and 36°. Larval activity continued slowly at 40°, and a few larvae emerged in the storage chamber.

From a sample of 300 fruits held 70 days, 12 larvae emerged in storage, or about 1 percent of the theoretical larval expectation for this lot. The first larva was recovered on the eleventh day and the last on the fiftieth day.

Further evidence supporting the statement that larval growth continues at 40° F. is indicated in figure 4, *B*. Larval emergence following refrigeration tended to be progressively earlier as the storage period was lengthened. This suggests simply that the population in the 40°

[7] See footnote 2.

lots was on the average further developed than that in the controls at the time the fruit was placed on the larval emergence rack; that is, the larvae grew while in storage. The occurrence of mortality might seem to complicate this evidence. Nevertheless, up to the twentieth day of the emergence period, more larvae emerged per 100 fruits from the 40° lots held 10, 15, 20, and 24 days than from the controls.

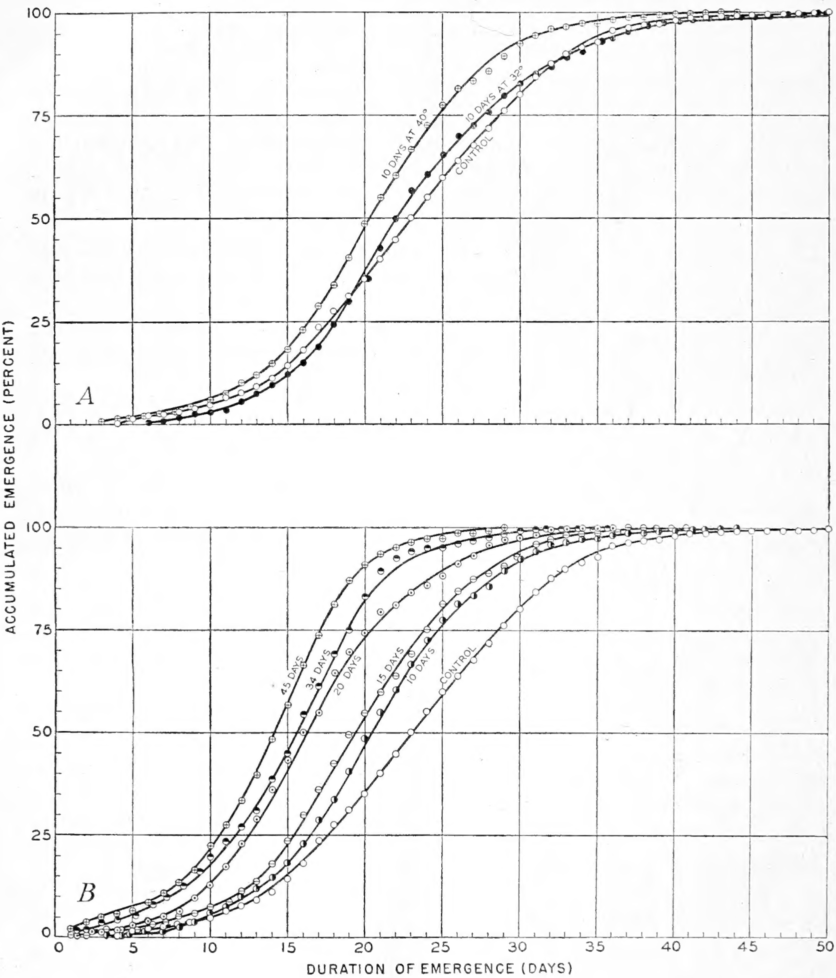

FIGURE 4.—Duration and rate of emergence of apple maggot larvae from various lots following exposure of the fruit to refrigeration: *A*, For 10 days at 32° and 40° F.; *B*, for various periods at 40°.

It was necessary to terminate the experiment at the end of the seventieth day, and, as may be seen in table 1, this storage period was insufficient to destroy all larvae. Had it been possible to obtain records extending beyond 70 days, it seems doubtful whether any data of practical significance would have been gained. Many of the fruits had rotted by this time and the remainder soon would have. Further-more, with the incidence of the rotting a question is raised as to how much of the mortality produced could be attributed to the temperature and how much to the rot.

After the completion of larval emergence, each fruit of the lots held 45, 50, 60, and 70 days was examined internally for the possible pressence of pupae. Only two partially transformed larvae were located and both of these were dead.

SUMMARY

Many foreign countries prohibit the importation of apples showing any degree of infestation by the apple maggot (*Rhagoletis pomonella* (Walsh)). Studies were therefore made to determine the possible use of cold storage as a disinfesting agent for fruit intended for sale in foreign markets. Fruit was placed in refrigeration rooms held at temperatures of approximately 32°, 36°, and 40° F.

Complete mortality of apple maggot eggs and larvae was effected within 32 days at an air temperature of 32° F. and within 45 days at 36°.

Larval progress through the fruit appeared to stop in storage temperatures of 32° and 36° F., but continued slowly at 40°, although all but a few individuals eventually died.

Since the air movement in the storage chamber was limited to that induced by gravity, the temperature of the fruit in the interior of the package remained nearly 1° F. above air temperature.

In commercial cold storages kept at approximately 32° F., 40 days should provide ample time for equalization of fruit and air temperatures, as well as for complete mortality, and allow a margin of safety.

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