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PICKING, HANDLING, AND REFRIGERATION OF RASPBERRIES AND STRAWBERRIES

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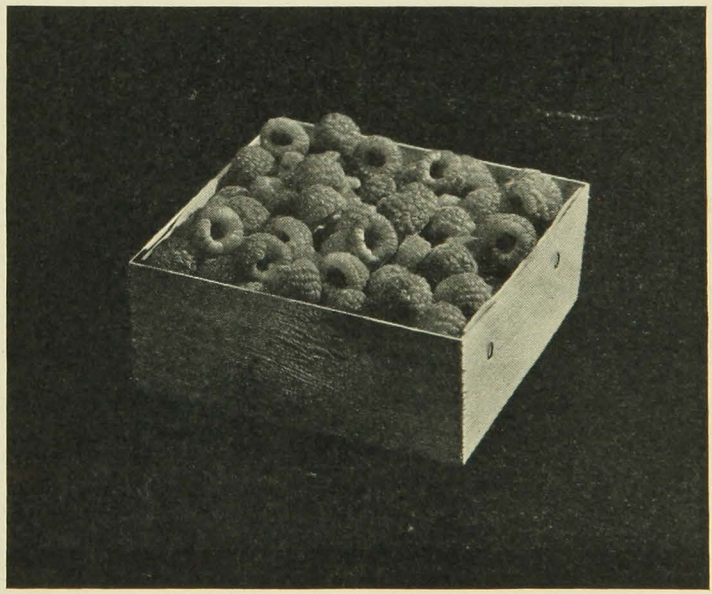


UNIVERSITY FARM, ST. PAUL

CONTENTS

PICKING, HANDLING, AND REFRIGERATION OF RASPBERRIES AND STRAWBERRIES

J. D. WINTER, W. H. ALDERMAN, and W. C. WAITE[1]

INTRODUCTION

The soil and the climate of Minnesota are particularly well adapted to the growing of small fruits. Red raspberry production expanded considerably following the development of a hardy and productive variety, the Latham, which was introduced in 1920 by the University of Minnesota Agricultural Experiment Station. A recent survey (1) shows that this variety and the Chief, a more recent introduction from the same station, constitute more than 90 per cent of the total red raspberry acreage in the state.

The last United States census reported 3,122 acres of raspberries in Minnesota in 1930. Most of these were red varieties. Less than 10 per cent were black varieties, and purple varieties are rarely grown. Since 1930, raspberry growing in this state has increased materially, and it is estimated that nearly 5,000 acres are now being grown, so that the state now ranks as one of the leading producers of red raspberries in the United States, with a production exceeded only by Oregon and Washington and possibly by New York.

Strawberry production in Minnesota, as compared with other sections, has not reached a large volume. The United States census shows 2,374 acres in Minnesota in 1930. But, before the drouth of 1934, production was increasing rapidly, the survey already referred to (1) showing an increase in bearing acreage of almost 50 per cent from 1933 to 1934.

The annual value of the Minnesota berry crop is about $1,000,000, and there is every indication that the volume of production will increase materially in the near future. Minnesota is at the northern limit of commercial production in the United States, and there should be a satisfactory market for larger production if adequate methods of distribution are provided.

[1] The authors wish to express their appreciation to the following: G. D. George for assistance in preparing the figures used in this publication; Dr. R. B. Harvey and R. H. Landon for equipment used in determining by means of electrical resistance thermometers, the rate of cooling of berries; Andrews Nursery Company for use of their specially built refrigerator and the donation of fruit used in experimental work on their premises; Bohn Refrigerator Company for technical data on refrigerator construction; Waldorf Paper Products Company for several types of paperboard boxes used in these experiments; Agricultural Engineering Division, Farm Building Section, University Farm, for preparation of the drawing of the farm refrigerator shown in this publication; Poultry Division, University Farm, for loan of the incubator used in these experiments.

Strawberries and raspberries are among the most perishable of horticultural crops. The problem of picking and handling these berries so that they may reach the market in the best possible condition will become increasingly important as it becomes necessary to find new outlets and a wider market. Moreover, it is likely that more careful attention to picking, grading, and handling will increase the demand for the fruits in the local markets.

This publication deals with the results of investigations made to determine the best methods of handling berries to prolong their keeping-quality. Particular emphasis is placed on berry temperatures and their relation to keeping-quality, especially with respect to the use of refrigeration by the grower. The rapidly increasing use of trucks for marketing berries over a rather wide area suggests the need, also, of careful attention to the trucking problem. The original data presented were obtained during the season of 1934.

EQUIPMENT AND METHODS

The keeping-quality of the fruit used in these experiments was determined on the basis of the length of time it remained in marketable condition or on the subsequent rate of development of mold.[2] In some instances only slight differences were apparent in the length of time the berries remained in marketable condition, but marked differences appeared in the subsequent development of mold.

The term "marketable condition" is used in this publication to denote berries in firm condition, without mold,[3] and of sufficiently good appearance to be salable under normal conditions. Berries should be in "usable" condition longer than in marketable condition. The percentage of decay in pint boxes of raspberries was determined by estimates, based on actual counts of sample boxes. The percentage of decay in strawberries was determined by counts of all boxes.

A standard poultry incubator of 540-egg capacity was used in most of the experiments, to keep berries at warm temperatures. The incubator was operated by electricity and was equipped with a fan for circulating the air. It was placed in a cellar and adjusted to maintain a constant temperature of 75 degrees F. A similar method for testing the keeping-quality of small fruits was suggested by Stevens (24). This method of testing the keeping-quality of berries at ordinary room temperatures seems to be dependable. It has the advantage of maintaining a uniform temperature at all times. It does not necessarily

[2] Dr. Carl J. Eide of the Division of Plant Pathology examined samples of the berries used in these experiments and found that the predominant mold was *Rhizopus nigricans* Ehrb.

[3] Tolerance not to exceed one per cent permitted in conformity with U. S. No. 1 grade.

follow that there will be a close correspondence in behavior at high and low temperatures, altho Stevens found a close correlation with blueberry varieties. Overholser (17) indicates that there is a close correlation in this respect between species of fruit, but not always between varieties within a given species.

In the spring of 1934 an experimental ice refrigerator was constructed at the University of Minnesota Fruit Breeding Farm, to cool and store berries under conditions that could be duplicated on many farms. The capacity was thirty-eight 24-pint raspberry crates or twenty-two 24-quart strawberry crates and the materials used in construction cost $35. Any grower, handy with saw and hammer, can build a refrigerator of this type. Details of construction are given elsewhere in this publication.

Shortly afterward, a refrigerator with a capacity of approximately 470 raspberry crates was constructed by one of the larger fruit growers in the state. This refrigerator was made available for experimental work through the courtesy of the owner. The Fruit Breeding Farm refrigerator was constructed with ice capacity of approximately 30 per cent of the available space and without a fan. The larger refrigerator was equipped with an automobile radiator fan driven by a one-half horsepower gasoline engine. The ice capacity of the larger refrigerator was approximately 10 per cent of the available space. The average temperature maintained in each refrigerator was 45 to 48 degrees F. These two refrigerators were used in the experiments where berries were held at cool temperatures.

A mechanical refrigerator at University Farm was used in one experiment in determining the rate of cooling of berries in different types of containers. A recent publication by Tavernetti (26) describes the construction and operation of mechanical refrigerators for farms. Under present Minnesota conditions the cost of mechanical refrigeration for operation only during the relatively short berry season would be too high to justify its use, regardless of whether this type of refrigeration is satisfactory for the purpose.

Air temperatures were measured by recording thermographs, supplemented by mercury thermometers. Humidity was determined by recording hydrographs, and checked by a sling psychrometer. Berry temperatures, except where noted, were determined by inserting a standard laboratory mercury thermometer into the center of a pint box of berries. The temperature recorded by the thermometer represents the temperature of the combined mass of berries and air in the pint box and is considered to be sufficiently accurate for the purpose of these experiments.

Information on certain phases of this project was obtained by means of a survey among retail merchants who handle berries in their stores. In June, 1934, 230 retail stores in Minneapolis were visited by two enumerators. Additional information, relating to refrigeration, was obtained by means of a questionnaire sent to representative berry-shipping associations in all sections of the United States. Thirty-one replies to this questionnaire were received from 14 different states.

VARIETY FIRMNESS

It is recognized that varieties of raspberries and strawberries differ in their keeping-quality. For this reason, the foundation of any effort to improve the condition of berries on the market rests upon the selection and use of suitable varieties. In this publication, the comparative keeping-quality of different varieties has been considered only incidentally. In five experiments where the varieties Chief and Latham were used under identical conditions there was no appreciable difference in their keeping-quality except that Chief retained a brighter color. Each variety remained in marketable condition approximately the same length of time, and each subsequently developed an equal percentage of moldy berries in each of the five experiments.

When comparing the firmness and keeping-quality of different strawberry varieties, the size of the berries also must be taken into account, because small berries of a variety are firmer than berries of larger size.

FRUIT INJURIES

Care in Picking Essential

Injuries due to picking and handling are an important factor in the keeping-quality of both raspberries and strawberries. To determine whether there may be a wide variation in the keeping-quality of berries from different pickers, two pints of raspberries were obtained from each of eight pickers. The pickers included boys, girls, men and women, from 10 to 50 years of age. None of the pickers knew that any test was contemplated. The berries were all picked from the same planting, at approximately the same time, and were kept under uniform conditions until the fruit became moldy. After nearly six days the amount of mold in the eight different lots was found to vary from 10 to 95 per cent, as is shown in Figure 1. While this experiment was not sufficiently extensive to warrant definite conclusions, it indicated the need for careful attention to the way in which the berries are picked. The three lots that kept in the best condition were picked by girls of 14 to 21 years of age.

It was observed that experienced pickers use three fingers in picking berries. This method distributes the pressure used in picking more evenly than when only two fingers are used. Young children are more likely to pick berries with two fingers, using too much pressure in picking. It is universally recognized that strawberries should be picked by pinching off the stem between the thumb and forefinger, leaving a part of the stem attached to the berry.

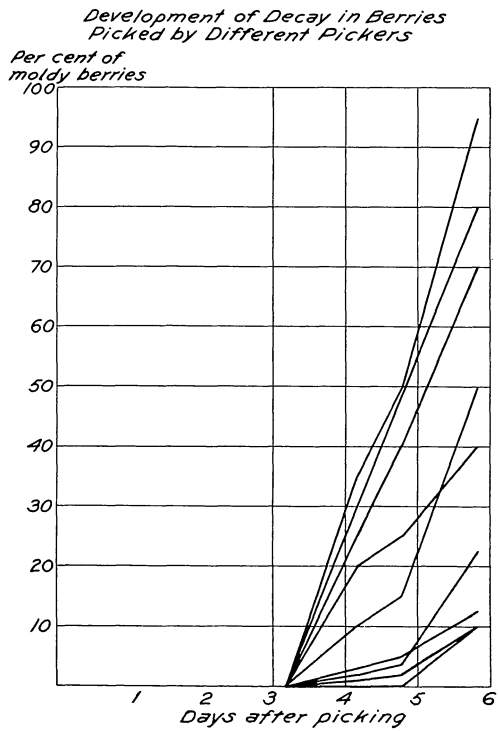


Fig. 1. Development of Decay in Berries Picked by Different Pickers

Berries frequently become crushed by holding too many in the hand before they are placed in the box. It is not advisable to empty filled or partly filled boxes, for re-sorting or grading, of any of the varieties of red raspberries and strawberries commonly grown in Minnesota. The berries should be sorted as they are picked, and the overripe berries and culls should be placed in separate containers. The practice of piling berries on a carrier of full boxes, to be taken off later and placed in other boxes, should not be permitted.

Ramsey (20) noted a wide variation in the development of decay in red raspberries from 12 different growers in the Puyallup Valley. In that instance, the amount of decay after four days in an iced car ranged from 1.3 per cent to 39.0 per cent, the difference apparently being due mainly to the character of the work required by the owner from his help. He found also that red raspberries when handled carefully showed only 2.2 per cent of decay after eight days in a refrigerated car, while comparable lots of commercially handled berries developed 26.7 per cent of decay during the same period. Similar results were obtained by Lloyd and Newell (14) with two varieties of strawberries.

Field-Damaged Berries Decay Rapidly

Injuries that most commonly affect the keeping-quality of raspberries occur during picking or in later handling of the berries. Infrequently a considerable amount of injury to raspberries will result from sunburn during excessively hot weather. The drupelets on a portion of the berry turn white as a result of this injury. One grower who kept a careful record of this injury reported a loss of 20 per cent for two pickings from one unusually hot day when the temperature went over 100 degrees F.

Injuries to strawberries by insects[4] and by birds cause the berries to decay rapidly. This type of damage is particularly prevalent during the fall. Table 1 shows the percentage of "leaky" berries that developed in damaged strawberries after 32 hours in an incubator at 75 degrees F. These berries were picked on September 19. Similar results were obtained with strawberries held under refrigeration, as shown in Figure 9. Obviously it is very desirable to cull out injured fruit.

Table 1

Development of Decay in Damaged Strawberries, Berries Held at Constant Temperature of 75 Degrees F.

Variety	Percentage of leaky berries after 32 hours		
	Berries free from damage	Berries damaged by insects or birds	Berries punctured with sharp stick
Mastodon	0	*	0
Wayzata	0	14	*
No. 999	0	80	*
No. 1166	0	75	*

* No test made.

It was observed that early injuries which had healed by the formation of a corky layer did not decay more rapidly than berries that were free from damage. One lot of berries was punctured with a sharp stick immediately after being picked. These punctures were of about the same size and extent as those in the damaged lots. The development of decay in the field-damaged berries was much greater than in those punctured after they were picked. It is assumed that decay organisms become established in field-damaged berries before they are picked. This would account for the much more rapid decay of field-damaged fruit.

[4] Much of this damage to berries is caused by crickets. These insects can be controlled by using a poison bran mash, made of the following ingredients:

	Small quantities	Large quantities
Bran	1 quart	100 pounds
Molasses	¼ cup	2 gallons
White arsenic or paris green	1 teaspoonful	5 pounds
Water	Enough to moisten	10 gallons

This should be scattered in the evening as thinly as possible around the plants, but not directly on the foliage. One or two applications usually are sufficient.

TIME AND FREQUENCY OF PICKING

Decay in Berries Picked at Different Hours

On July 10 the same person picked a pint of raspberries at hourly intervals during the day. All the berries were kept in a berry shed until 6 p.m. and then placed in an incubator at 75 degrees F. The development of decay in these berries at 8 a.m. on the third, fourth, and fifth days is shown in Figure 2. The difference in the amount of mold visible on the third day was not great, but marked differences appeared on the fourth and fifth days. The most mold appeared on berries picked between 10 a.m. and 1 p.m. Berries picked during the latter part of the afternoon showed much less mold than those picked during the middle of the day. Similar results were obtained with raspberries cooled for relatively short periods, as shown in Figure 3.

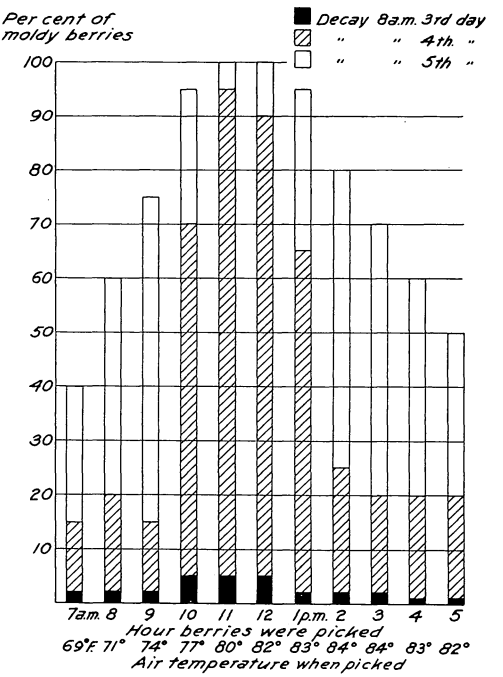


Fig. 2. Development of Decay in Uncooled Berries Picked at Different Hours, Latham Variety

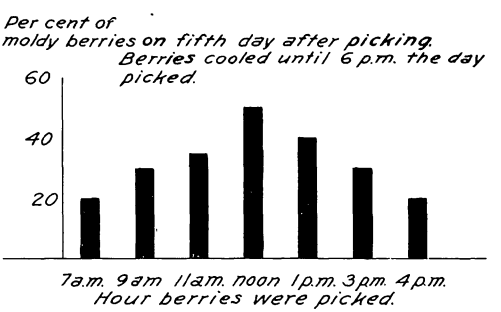


Fig. 3. Development of Decay in Berries Picked at Different Hours and Cooled For Different Periods, Latham Variety

Another lot of raspberries, picked at hourly intervals, was placed at once in a refrigerator and kept there for six days. At the end of that period the berries were placed in a basement room at 70 to 76 degrees F. On the following day no significant difference was apparent in these berries. There was no mold. The de-

velopment of mold began rather uniformly in all lots on the eighth day, and on the tenth day it had reached 90 to 100 per cent in all lots after 10 a.m. This lot picked before 10 a.m. averaged 60 to 70 per cent.

The foregoing data show that raspberries picked in the early part of the day and in the late part of the afternoon kept better than those picked in the middle of the day, when the berries were not cooled by refrigeration or were cooled for relatively short periods. When the berries were held in a refrigerator for six days there was no significant difference in their keeping-quality.

Berries picked in the later part of the afternoon were on the bushes a greater length of time and consequently in storage a shorter time than those picked earlier in the day. Experiments (2, 9, 10, 15) with other fruits have shown that, when the picked fruit is held at the prevailing air temperature, the ripening process continues at a faster rate after picking than before. This probably explains why berries picked in the later part of the afternoon kept better than those picked in the middle of the day. Rendle (21) calls attention to the remarkable rapidity of the ripening process in raspberries. He says that one of the effects of the ripening process in freshly picked raspberries is a rapid change in the pectin substances with destruction of jelling powers, and he presents evidence that this jelling ability completely disappears after 24 hours storage at normal summer room temperatures.

Berries Must Be Picked Promptly

Most raspberries and strawberries grown in Minnesota are picked every other day. It is customary, most of the time, to pick one half the planting one day and the other half the following day. In hot weather, in the height of the raspberry season, it is often desirable to pick the entire planting daily to obtain berries of uniformly good marketable condition. A few overripe berries will cause rapid decay at ordinary summer temperatures.

Enough pickers must be available to pick the crop as promptly as conditions warrant. The number needed for each acre depends on the size of the crop. For raspberries, the number normally is seven to eight pickers an acre, and, for strawberries, about five or six.

MATURITY OF THE FRUIT

Berry growers are well aware that the conditions under which berries are marketed determine the proper degree of maturity at which the fruit should be picked. A number of factors must be considered, such as the variety, distance to market, and weather conditions at the time of picking.

Latham raspberries, picked when pink-ripe and held in an incubator at 75 degrees F., were found to keep in marketable condition from one to one and a half days longer than berries of the same variety picked at the ordinary, firm-ripe stage of maturity. Similar berries, picked pink-ripe and held under ice refrigeration at 45 to 48 degrees F. for five days, kept in marketable condition about one day longer than berries picked when firm-ripe and stored under identical conditions.

A number of the retail merchants, visited in the survey of Minneapolis stores, mentioned the need for the more careful picking of strawberries at a proper stage of maturity, so that fewer berries would be overripe when they were received. All merchants were asked how Minnesota strawberries kept as compared with berries shipped in. Out of 230 replies to this question, 36 per cent said that Minnesota berries kept better, 44 per cent said that Minnesota berries kept just as well, and 20 per cent said the local berries did not keep so well as berries shipped in. The replies showed only a very slight advantage for the home-grown berries.

It should be possible to pick and handle Minnesota-grown berries in such a way that they will keep decidedly better than berries shipped from a distance. The average amount of spoilage reported in this survey was 6.4 per cent. A large majority of the stores used refrigeration for keeping berries in good condition until sold. Only 17 per cent did not use refrigeration.

WEATHER CONDITIONS DURING RIPENING PERIOD

Effect of Rainfall on Keeping-quality

Common experience shows that berries picked while wet do not keep well. The poor keeping-quality of such berries was shown by several pints of raspberries picked wet in the early morning of July 17, after heavy rainfall on July 15 and after rain again on July 16. These berries were placed in a basement room at 70 to 76 degrees F. After 48 hours the berries were covered with mold and about 35 per cent were badly decayed.

A striking contrast was observed between these berries and 11 pints of berries that were picked in dry weather and stored in the same room. These 11 pints were picked one week earlier (July 10), and were held in a refrigerator until noon of July 16. Then, 19 hours before the wet berries were picked, they were placed in the same basement room. When the wet berries had become badly decayed, 48 hours after picking, the berries picked on July 10 showed much less mold, and were still moderately firm, and none were badly decayed. The difference

was very marked, in view of the fact that the berries picked on July 10 had been in the warm room nearly one day longer than the berries picked on July 17.

The duration and amount of rainfall, undoubtedly, has an effect on keeping-quality that is entirely distinct from that of the moisture on the berries. Berries picked following a prolonged period of rain are not properly matured and lack firmness. Kimbrough (12), in working with fertilizer treatments on strawberries, found that the moisture content of picked berries was high when rainfall was heavy, and low when rainfall was light, producing a more marked effect on the composition of berries than the various fertilizer treatments that were given.

Picking Berries Wet from Dew

Stevens (23) says that observations in four New England states indicate that strawberries picked early in the morning generally kept better, even tho wet, than similar berries picked later. He refers to berries wet from dew. Reports from various sources agree that strawberries picked while wet with dew will keep satisfactorily, if given an opportunity to dry off before the crates are filled and the covers nailed on. While there is little published information as to picking raspberries that are wet with dew, it is generally considered that the practice is not desirable.

REDUCING BERRY TEMPERATURES BY AIR-COOLING

Temperature of Freshly Picked Berries

On three different occasions the temperature of freshly picked raspberries was measured at hourly intervals during the day. The hourly temperatures recorded are shown in Figure 4. The data show that freshly picked raspberries normally have a temperature above that of the surrounding air except in the early morning. The maximum difference was 9 degrees F. Stevens and Wilcox (25) report similar observations with strawberries and other small fruits.

The temperature of freshly picked raspberries was compared also with that of berries picked at 7 a.m. and held in a berry shed during the day. Hourly readings were taken and these are included in the data shown in Figure 4. A very decided difference in temperature was recorded during the middle of the day, with a maximum difference of 17 degrees F.

No appreciable difference exists between the temperature of the berries as they come from the bush and their temperature after a full pint box has been picked and brought to the berry shed. This was

determined on three different occasions by picking berries directly into a pint box in which a thermometer had been inserted, care being taken to keep this pint box in the shade during the picking.

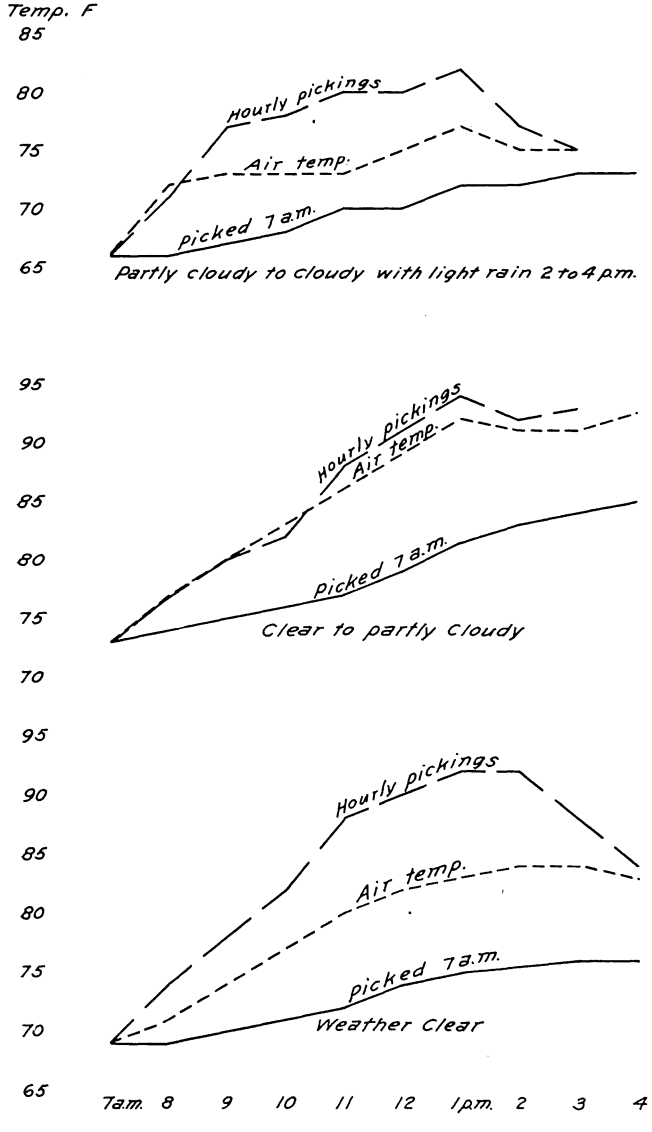


Fig. 4. Temperature of Raspberries Picked at Hourly Intervals During the Day

The temperature of berries picked at 7 a.m. and held in a berry shed during the day is included for comparison.

These data show conclusively that berries picked early in the day are cooler than those picked later, and that when early-picked berries are held in a berry shed they remain very much cooler during the day than those that are picked later during the same day.

Effect of Ventilation on Rate of Cooling

Berries coming directly from the field during the heat of the day and held in a ventilated berry shed will cool to a temperature below that of the air. Figure 5 (A and B) shows the temperature of raspberries picked at different hours and held in a roadside market shed

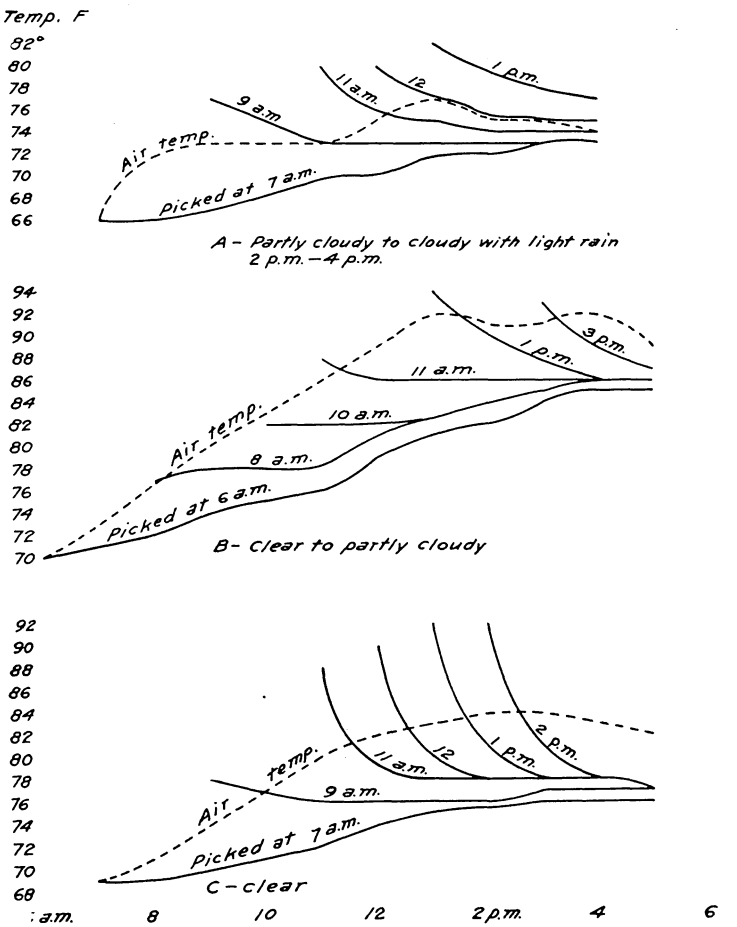


Fig. 5. Temperature of Raspberries Picked at Different Hours of the Day and Held in Berry Shed

Lots A and B were held in a poorly ventilated shed; Lot C, in a well ventilated shed.

during the day. This shed is almost completely enclosed on three sides and partly enclosed on the fourth side. Figure 5 (C) shows the temperature of berries picked in a similar manner and held in a well ventilated berry shed during the day. It will be noted that the berries cooled more rapidly in the well ventilated shed, which consisted only of a roof and a few boards on the south side.

In each instance practically all the cooling took place during the first two hours after picking. In the well ventilated shed the rate of cooling averaged 5 to 8 degrees F. per hour for the first two hours. While these tests were made with single pint lots of berries, a similar rate of cooling occurred in the top deck of full crates, as indicated in Table 3.

This cooling is mainly due to evaporation and is accompanied by loss of weight. On one of the hottest days of the year, three pints of raspberries, picked between 9 and 10 a.m., were weighed at 10:45 a.m. The loss of weight was recorded at 2:45 and 4:45 p.m., and at 8:00 a.m. the next day. These berries were placed in the shade about three feet above the ground, under a tree. Table 2 shows the loss of weight at different periods, and also the loss of weight in berries placed at another time in a refrigerator. The berries kept in the open lost 12.8 per cent of their weight in 23 hours and settled appreciably in the boxes. A prolonged period of exposure evidently is detrimental, and may result in a loss of weight that will bring the berries below legal requirements. Similar berries in a refrigerator lost only 1.76 per cent in weight in 43 hours.

Table 2

Loss of Weight of Raspberries

A. Berries Placed Under Shade of Tree				
Hour	10:45 a.m. July 22	2:45 p.m. July 22	4:45 p.m. July 22	7:45 a.m. July 23
Air temperature	98°	104°	*	*
Net weight, 3 pints berries....	1028.0 gms.	967.6 gms.	947.1 gms.	896.0 gms.
Total loss of weight.....	.....	60.4 gms.	80.9 gms.	132.0 gms.
Per cent loss of weight.....	.....	5.9	7.9	12.8

B. Berries Placed in Refrigerator at 45 to 48° F.			
Hour	4 p.m. August 3	9 a.m. August 4	11 a.m. August 5
Net weight, 1 pint berries.....	318.7 gms.	316.3 gms.	313.1 gms.
Total loss of weight.....	.....	2.4 gms.	5.6 gms.
Per cent loss of weight.....	.....	0.75	1.76

* No record.

The effect of ventilation on berry temperatures was shown by recording the rate of cooling in freshly picked berries in different places. The data are given in Figure 6 and show very clearly that berries cool

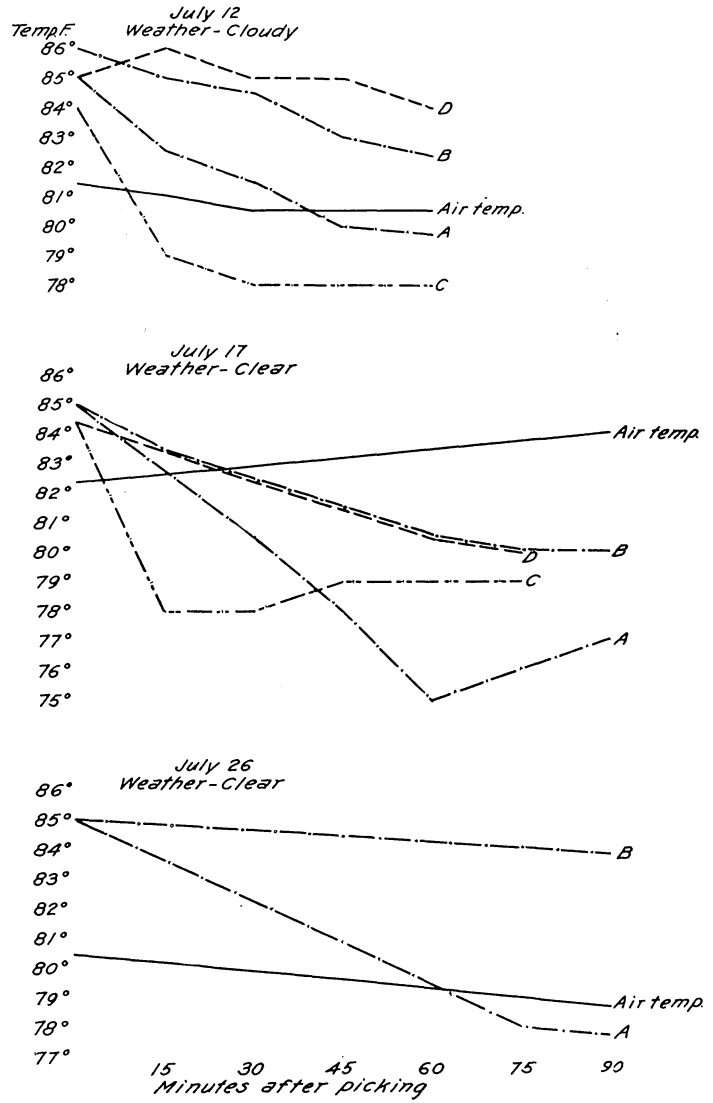


Fig. 6. Rate of Cooling of Berries Picked at the Same Time and Held under Different Conditions

A, in open berry shed exposed to wind; B, in open berry shed protected from wind; C, in open berry shed under six-volt fan; D, on the ground in shade of berry bush.

most rapidly where ventilation is the best. Cooling was decidedly less rapid in an enclosed shed, even with two windows and a door open. Berries cooled very slowly when placed in a pint box on the ground under the shade of a berry bush where they were sheltered from the

wind. The most rapid cooling occured in berries placed directly under a six-volt automobile fan. In this position the air movement from the fan was the principal factor, as the berries were sheltered from any breeze blowing at the time.

The best type of berry shed obviously is one with only a roof and enough protection on the south side to protect the berries from the sun.

Rate of Cooling in a Cellar

Temperature data shown in Table 3 indicate that raspberries picked during the heat of the day and placed at once in a cool cellar do not cool so rapidly at first as similar berries kept in a well ventilated and shaded place above ground where there is some movement of air. Table 3 shows the comparative rate of cooling for a period of 90 minutes on four different occasions. The temperatures recorded were taken in the center of the top deck of pint boxes when crate and half-crate lots were used. In each instance the first temperatures were taken within one hour after the berries were picked. As berries do not come from the fields at uniform temperatures, it was not possible on each occasion to select crates with berries in the top deck at exactly the same temperatures.

Table 3

Comparative Rates of Cooling of Raspberries in a Cool Cellar and in the Shade Above Ground

Air temperature	Wind	Quantity of fruit	Location of fruit	Temperature of berries at half-hour intervals				Degrees cooled first hour
				0	½	1	1½	
91 to 94° F.	Very light	3 pints	In shade under tree	92.0° F.	87.5° F.	86.0° F.	85.0° F.	6.0° F.
			In cellar at 75° F.	92.0° F.	86.5° F.	82.5° F.	80.0° F.	9.5° F.
98 to 100° F.	Light	1 crate	In shade under tree	93.0° F.	85.5° F.	83.0° F.	83.0° F.	10.0° F.
			In cellar at 75° F.	87.0° F.	85.0° F.	84.0° F.	83.0° F.	3.0° F.
78 to 82° F.	Brisk	½ crate	In shade under tree	75.0° F.	72.5° F.	72.5° F.	73.0° F.	2.5° F.
			In cellar at 69° F.	75.0° F.	75.0° F.	75.0° F.	75.0° F.	0.0° F.
86 to 88° F.	Brisk	1 crate	In shade under tree	86.0° F.	82.0° F.	79.0° F.	78.5° F.	7.0° F.
			In cellar at 69° F.	90.5° F.	88.5° F.	87.0° F.	85.0° F.	3.5° F.

The rate of cooling in the cellar was decidedly slower on the three occasions when there was a light to brisk wind. On July 20, when the temperature outdoors was high, with practically no movement of air and a relative humidity of 61 per cent, the berries in the cellar cooled

more rapidly. On that day the smaller quantity of fruit used undoubtedly accounted to a large extent for the more rapid rate of cooling in the cellar than in the other three experiments. The rate of cooling of freshly picked berries is determined largely by the quantity of fruit, the rate of air movement, and the difference in temperature between the air and the berries. The relative humidity of the air and the variety of the berries are also factors.

The placing of berries in a cellar where only air temperature is favorable does not necessarily produce the most rapid cooling of the berries or best preserve their keeping-quality. After about two hours, berries in a cellar may continue to cool slowly if the temperature is sufficiently low, but further cooling above ground is not likely during the heat of the day.

The average cellar cannot be considered a cool storage place for berries, and it will not approach the temperatures obtained from ice refrigeration. The air temperature of an ordinary cellar during the raspberry season is 70 to 75 degrees F. After the fruit has cooled to about 80 degrees F. the rate of cooling becomes extremely slow, as shown in Table 4. Data shown in Tables 3 and 4 indicate that raspberries placed in the average cellar are not likely to cool much below 75 degrees F. The heat of respiration probably prevents the berries from reaching the actual cellar temperature, unless a fan is used. On July 23, a crate of raspberries in the cellar was placed in front of a 10-inch house fan. The temperature of the berries in the top deck dropped in 30 minutes from 80.5 to 74 degrees F., the cellar temperature being 75 degrees F.

Table 4

Rate of Cooling of Raspberries in a Cellar

Temperature of cellar	Temperature of fruit when picked	Temperature of berries at hourly intervals after picking				
		1 hour	2 hours	3 hours	4 hours	5 hours
75° F.	98.5° F.	89.0° F.	81.0° F.	77.5° F.	*	*
75° F.	*	86.0° F.	83.0° F.	81.0° F.	78.5° F.	77.0° F.
69° F.	90.5° F.	87.0° F.	83.5° F.	80.5° F.	*	*

* No record.

The relative humidity in the average cellar is generally higher than that above ground. No attempt was made to study the effect of this higher humidity at the ordinary cellar temperatures on the keeping-quality of berries. According to the experience of some growers, berries kept in a cellar during the day and night are likely to develop mold more readily than berries kept above ground. It is probable that berries placed in a cellar during the day should be removed to a well ventilated position above the ground during the night.

COOLING BERRIES BY REFRIGERATION

The temperature at which berries are held after picking is one of the principal factors that determines their market condition, especially if a considerable time elapses between picking and marketing. Experiments (4) have shown that, within normal storage temperatures, for each rise in temperature of about 15 degrees F., the keeping-quality of berries, other things being equal, is reduced one-half. Promptness and rapidity of cooling bcome increasingly important as the time required for marketing increases.

Refrigeration has been used for many years in the car-lot movement of raspberries and strawberries. At first this refrigeration consisted of loading the berries into refrigerator cars that had been iced for 12 hours or more before loading. More recently, portable equipment for rapidly reducing the temperature of fruit after loading has come into use. Rapid cooling is obtained by means of fans which force the air through the ice bunkers. A number of different types of apparatus have been used for this purpose. One of these, described by Galloway (6), is protected by Public Service Patent No. 1696441.

The rapid cooling of fruit before shipment is referred to as pre-cooling. Equipment to pre-cool berries before they are loaded into a car is available at only a comparatively few shipping points.

Information received from 29 berry-shipping associations shows that 13 of the associations pre-cooled the berries before shipment and 16 did not. Two of the latter said that pre-cooling equipment would be used the following season. Twenty-one of these associations said that part of their shipments were made by truck, but only two of these pre-cooled their truck shipments. In two instances, both in the Pacific Northwest, replies said that trucks equipped with mechanical refrigeration were used.

The value of pre-cooling berries is shown by Lloyd and Newell (13), Overholser and Moses (18), Ramsey (20), and others. Evidence accumulated by these investigations indicates that the more rapidly a highly perishable product can be cooled, the greater the possibility of extending the storage period.

Refrigeration on Premises of the Grower

Comparatively little attention has been given to the possibility of cooling berries by refrigeration on the premises of the grower. In 1934, tests were made to determine the effect of different periods of refrigeration on the keeping-quality of raspberries. In these experiments the berries were cooled on the grower's premises, using the two refrigerators described on page 7. Figures 7 and 8 show how long the raspberries remained in marketable condition when held under refrigeration for

various periods. The data in Figure 8 constitute a part of the data shown in Figure 7, and are arranged so that lots picked at the same time under exactly similar conditions are grouped together. Unfortunately, drouth conditions of 1934 made it impossible to obtain strawberries of the spring crop for a similar test.

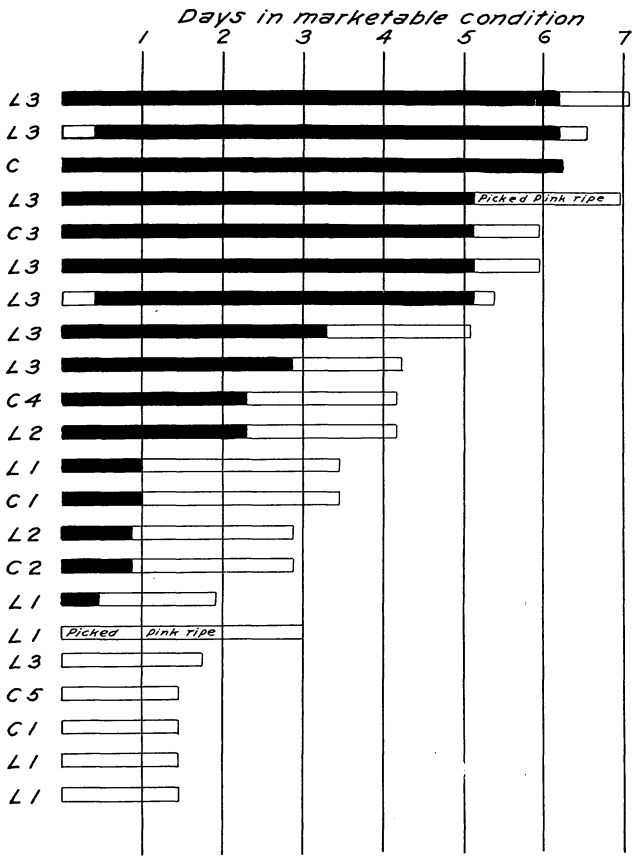


Fig. 7. Number of Days July Pickings of Raspberries Remained in Marketable Condition When Held For Various Periods Under Ice Refrigeration and When Uncooled

Shaded area, hours in refrigerator at approximately 45 to 48 degrees F.; unshaded area, hours not in refrigerator. The numerals indicate the place in which the berries were kept when not in the refrigerator: 1, an incubator at 75° F.; 2, a cellar at 73° F.; 3, a basement room at 70 to 76° F.; 4, a storage shed at 54 to 86° F.; 5, a roadside market shed. The letter preceding the number indicates the variety used: C, Chief; L, Latham.

When these experiments were made, the weather was dry and the berries in the field were firm. Under such conditions it was shown very clearly that ice refrigeration could be used by the grower to pro-

long the marketable condition of his berries. The data presented in Figures 7 and 8 show:

1. Red raspberries may be kept in marketable condition by refrigeration for at least 5 to 7 days.

2. Berries kept under refrigeration for 2 to 3 days remained in marketable condition after their removal from the refrigerator as long or even longer than berries that were not cooled.

3. After the first 24 hours, the longer the raspberries were held under refrigeration, the shorter was the length of time they remained in marketable condition after their removal from the refrigerator.

4. Under the conditions of these experiments, the maximum length of time berries remained in marketable condition was 59 hours, after 24 hours in the refrigerator. The minimum was 8 hours, after 7 days of refrigeration.

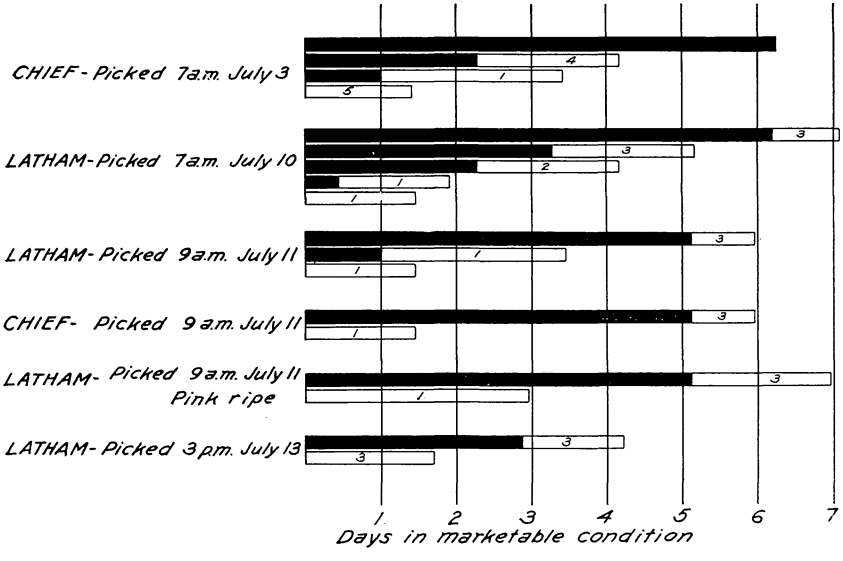


Fig. 8. Effect of Ice Refrigeration on the Number of Days Raspberries Remained in Marketable Condition When Picked Under Identical Conditions

Shaded area, hours in refrigerator at approximately 45 to 48° F.; unshaded area, hours not in refrigerator. The numerals show the place where the berries were kept when not in the refrigerator, as described in Figure 7.

A limited test of the keeping-quality of fall-bearing strawberries under ice refrigeration was made with a small model refrigerator. This refrigerator maintained an average temperature of 40 to 44 degrees F., which is several degrees lower than that of the refrigerators used for raspberries. The principal variety used was Wayzata, altho a few lots of several other varieties were included. Only enough berries to cover the bottom of a pint box were used, so that the condition of each berry

could be observed without disturbing the other berries. Under such conditions, berries kept in marketable condition from 8 to 12 days, as shown in Figure 9, except damaged berries, which kept only a relatively short time. Berries picked at the same time under identical conditions were placed in an incubator and held at 75 degrees F. The length of time these berries remained in marketable condition is also shown in Figure 9.

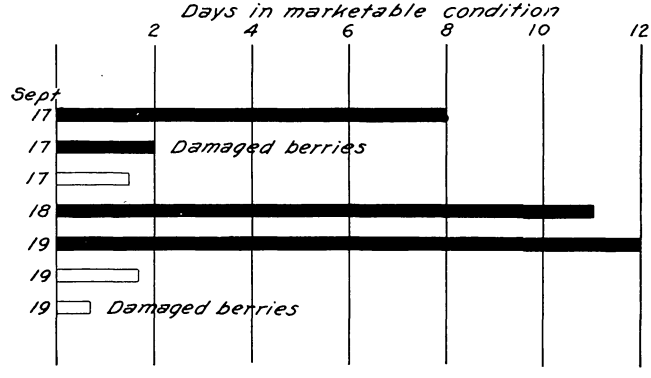


Fig. 9. Number of Days Strawberries Remained in Marketable Condition When Held Under Ice Refrigeration and When Not Cooled. Shaded area, hours in refrigerator at 40 to 44 degrees F.; unshaded area, hours in incubator at 75 degrees F. Variety, Wayzata.

Further information, obtained from truckers who purchased raspberries in considerable quantities taken from the larger refrigerator, indicated that the cooled berries kept in much better condition than uncooled berries, when hauled to distant towns. The truckers showed a marked preference for berries that were placed in the refrigerator soon after being picked and stored there until early the next morning. These observations are supported by the work of Hawkins and Sando (11), who found that blackberries, cherries, strawberries, and raspberries were much less easily punctured when cool than when warm.

Temperature and Relative Humidity

Recording thermographs showed that each of the two refrigerators used for most of the experiments maintained an average temperature of 45 to 48 degrees F. Higher temperatures were recorded for a time, when large quantities of fruit were being cooled. Recording hydrographs showed the average relative humidity to be between 70 and 80 per cent. The temperature and humidity conditions appeared to be satisfactory, as there was no evidence at any time of excessive moisture and the berries did not develop mold readily. The relative humidity

of the ordinary household ice refrigerator is between 70 and 80 per cent, and that of mechanically cooled refrigerators of the same type is considerably lower. A very satisfactory distribution of temperature within these refrigerators was obtained, as shown in Table 5.

Table 5

Distribution of Temperature in Small Refrigerator Without Fan and in Large Refrigerator With Fan

Distance above floor level	Refrigerator without fan		Refrigerator with fan operating
	July 31	August 1	July 10
2 inches	46.5° F.	44.5° F.	48.0° F.
3 feet, 8 inches	48.0° F.	45.5° F.	*
5 feet, 4 inches	*	*	47.0° F.

* No record.

In commercial cold storage houses it has been observed (19) "that large quantities of one kind of vegetable tend to change the humidity of the room to a certain value which in most cases is near the optimum of the particular crop involved." Rose (22) recommends for berries a relative humidity of 80 to 85 per cent at a temperature of 31 to 32 degrees F.

Promptness in cooling to temperatures of 50 degrees F. or below affects the germination of fungi that produce decay, some of which can grow slowly at a temperature as low as 32 degrees F., but require a higher temperature for the germination of the spores. Brooks (3) states that at 50 degrees F. Rhizopus rot is seldom able to start on stone fruits. He says this rot makes as good a start in one day at 85 degrees F. as in three days at 59 degrees or in ten days at 50 degrees. Gray or black mold (Botrytis) and blue mold (Penicillium) also are common mold fungi that develop in berries, according to Ramsey (20).

Rate of Cooling With and Without a Fan

Figure 10 shows the rate of cooling of raspberries under refrigeration with and without a fan. The quantities used were crate and half-crate lots. The rate of cooling was decidedly faster in the refrigerator equipped with a fan, averaging 15 to 20 degrees F. for the first hour, and from 2 to 8 degrees per hour thereafter. In the refrigerator without a fan the rate of cooling averaged 4 to 6 degrees F. per hour.

The rate of cooling is determined largely by the quantity and temperature of the fruit. Figure 11 shows the rate with a capacity load of 466 crates of raspberries and a fan in operation. In this test, cooling averaged about 5 degrees F. per hour.

Overholser and Moses (18) showed that small fruits cool somewhat more rapidly than large fruits when placed under refrigeration. Table 6 shows the temperature of raspberries after varying periods of cooling in the refrigerators used in these experiments. The heat of respiration probably accounts to a large extent for the fact that the fruit temperature remained somewhat above that of the surrounding air in the refrigerator.

Table 6

Minimum Temperatures Reached by Raspberries During Different Periods of Storage in an Ice Refrigerator

No.	Temperature of refrigerator	Fan	Initial temperature of fruit	Hours in refrigerator	Location of fruit	Fruit temperature after 1 hour	Final temperature of fruit
1	46-47° F.	No fan	73° F.	8	Near floor	68° F.	52° F.
2	45-46° F.	No fan	82° F.	7	Near floor	75° F.	52° F.
3	46-51° F.	Operating	77° F.	4	Near floor	53° F.	48° F.
4	46-48° F.	Operating	86° F.	2	Near floor	56° F.	48° F.
5	41-51° F.	Operating	64° F.	3½	Near floor	52° F.	44° F.
6	46-48° F.	Operating	71° F.	1½	Near floor	53° F.	48° F.
7	46-48° F.	No fan	*	17	Near floor	*	48° F.
8	46-48° F.	No fan	*	17	42 inches above floor	*	48° F.

* No record.

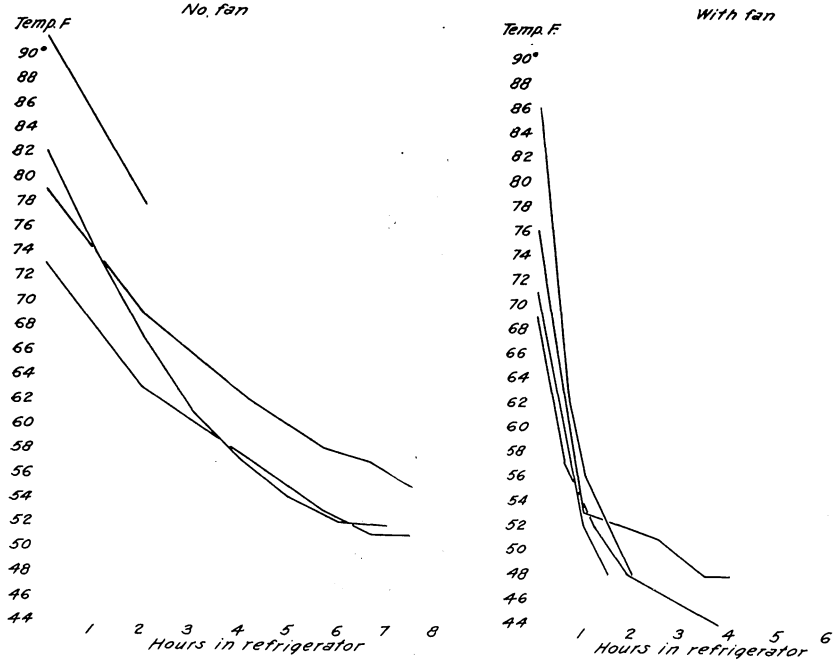


Fig. 10. Rate of Cooling of Raspberries under Refrigeration With and Without a Fan

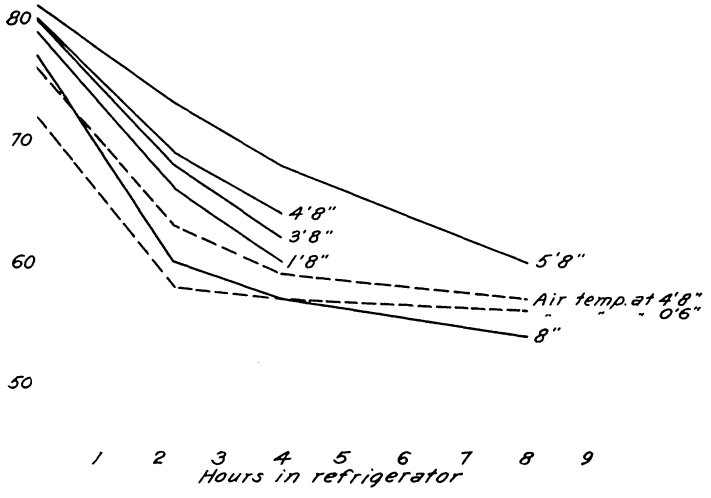


Fig. 11. Rate of Cooling of Raspberries at Different Heights Above the Floor in Refrigerator With Capacity Load of 466 Crates
Ice consumed, 2,200 pounds in 12 hours.

Rate of Cooling in Different Containers

Two types of raspberry crates are used commonly in Minnesota, one with dividers between the top and bottom decks known as the "ventilated crate," and the other, without any divider, known as the "old-style crate." Both use the same size of square, Hallock-type pint box. Another crate, in general use in the Pacific Coast region, is similar to the ventilated crate described above, but takes pint boxes that are not so deep but are larger in other dimensions.

The rate of cooling of raspberries in the bottom deck of these three types of containers was determined by means of electrical resistance thermometers. In each instance, the readings were taken inside a berry in the center of a pint box. Half a crate of fruit was used for each lot. The rate of cooling was measured in a mechanically cooled refrigerator. A 10-inch house fan, operating at slow speed, circulated the air in the refrigerator.

The rate of cooling, as shown in Figure 12, was decidedly more rapid in both types of ventilated crates, which showed approximately the same rate of cooling. It required 4 hours for the berries in the bottom deck of the "old-style" crate to cool as much as similar berries in the standard ventilated crate cooled in 2½ hours. Undoubtedly the difference would be greater with larger quantities of fruit.

The rate of cooling of raspberries in different types of pint boxes was measured on three different occasions, as shown in Table 7. Temperatures in single pint lots, recorded on July 11 and 12, were

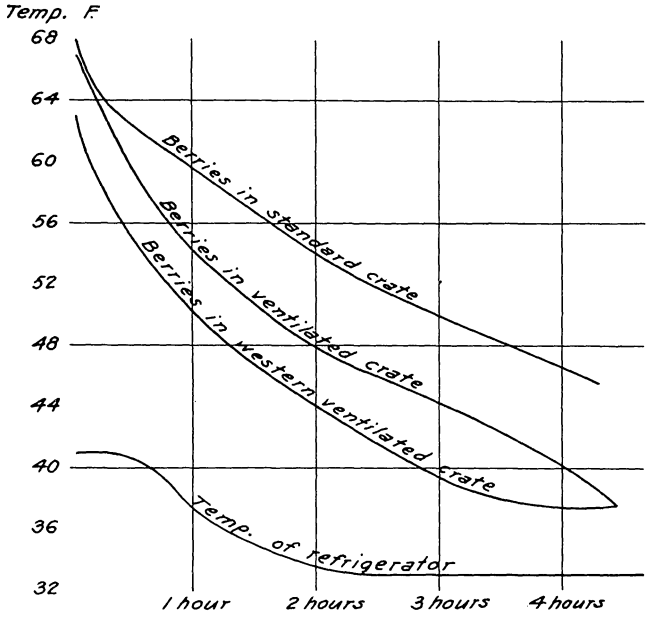


Fig. 12. Rate of Cooling of Raspberries in Bottom Deck of Three Different Types of Crates

Table 7

Rate of Cooling of Raspberries in Different Types of Pint Boxes

Date	Type of box	Material	Temperature of berries at half-hour intervals						
			0	½	1	1½	2	2½	3
July 11	American	Paper board	76.0° F.	74.5° F.	73.0° F.	69.0° F.	62.0° F.	57.0° F.	53.0° F.
	Hallock	Wood veneer	76.0° F.	72.5° F.	70.0° F.	64.0° F.	57.0° F.	52.0° F.	48.0° F.
July 12	American	Paper board	80.0° F.	76.0° F.	71.0° F.	60.0° F.	53.0° F.	*	*
	Hallock	Paper board	80.0° F.	75.0° F.	68.0° F.	59.0° F.	54.0° F.	*	*
	Hallock	Wood veneer	80.0° F.	74.0° F.	66.0° F.	57.0° F.	51.0° F.	*	*
July 18	American	Paper board	64.0° F.	59.0° F.	56.0° F.	53.0° F.	50.5° F.	48.0° F.	46.0° F.
	Hallock	Paper board	64.0° F.	58.0° F.	55.5° F.	53.0° F.	50.5° F.	48.0° F.	46.5° F.
	Hallock	Wood veneer	64.0° F.	56.0° F.	53.0° F.	50.0° F.	48.0° F.	46.0° F.	44.0° F.
	Hallock (western)	Wood veneer	64 0° F.	54.0° F.	50.0° F.	47.0° F.	44.0° F.	42.0° F.	40.5° F.

* No record.

taken in an ice refrigerator by means of mercury thermometers. Temperatures in half-crate lots, recorded on July 18, were taken in a mechanically cooled refrigerator with electrical resistance thermometers. Wood-veneer boxes showed a distinct superiority over paperboard containers in the rate of cooling. With larger quantities of fruit, the difference would probably be greater.

Delay in Cooling

To determine the effect of delay in cooling, eight pints of raspberries were picked by each of two pickers between 6 a.m. and 7 a.m. on July 3. One pint from each picker was placed at once in the refrigerator, and the remaining berries were kept in a roadside market shed. The maximum air temperature during the day was 90 degrees F. At regular intervals two pints were placed in the refrigerator; the last lot at 7 a.m. the following day. No appreciable difference in keeping quality was observed in the first three lots which were all in the refrig-

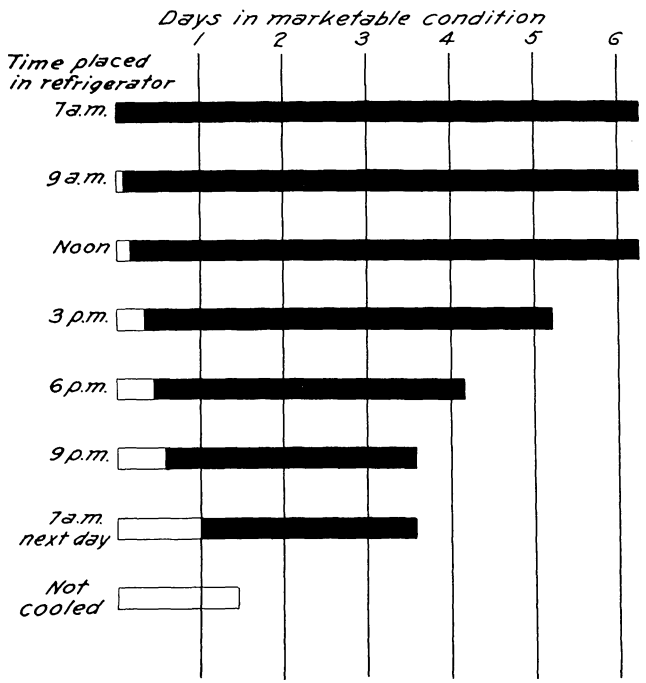


Fig. 13. Effect of Delayed Refrigeration Upon the Number of Hours Berries Remained in Marketable Condition after Being Placed in Refrigerator

Shaded area, hours in refrigerator at approximately 45 to 48 degrees F.; unshaded area, hours in roadside market shed. These berries were picked between 6 a.m. and 7 a.m. on July 3. Variety, Chief.

erator by noon. Berries that went into the refrigerator later than noon showed a decided loss in keeping-quality, as shown in Figures 13 and 14.

Similar results were observed by Lloyd and Newell (14), who showed that delay in loading strawberries into refrigerator cars adversely affects their carrying-quality. In their experiments, the berries were not picked at the same time but were picked at intervals of 8 hours, 24 hours, and 32 hours before loading.

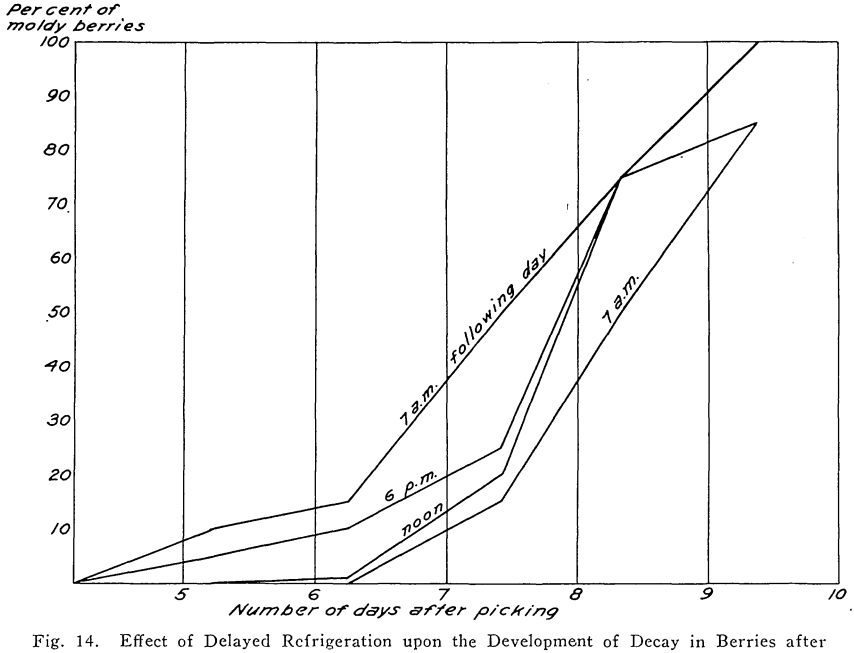


Fig. 14. Effect of Delayed Refrigeration upon the Development of Decay in Berries after being Placed in Refrigerator

These are the same berries as shown in Fig. 13. The graph indicates the development of decay up to and including the ninth day after picking.

It is apparent that berries should be cooled promptly. When the berries are unusually warm, the temperature can be reduced by air-cooling for an initial period of about two hours, as shown previously in this publication. The saving in ice through air-cooling would amount to about 12 pounds for each ten crates of raspberries cooled 10 degrees F. Air-cooling in a well ventilated berry shed resulted in reducing the temperature of berries from 10 to 14 degrees F. during the heat of the day.

It is possible, also, that a period of air-cooling would be beneficial in reducing excess moisture, and that this would be advisable before placing the berries in refrigeration. Berries with a high moisture content may keep better if air-cooled before they are placed in a refrigerator, but no direct information regarding this is available.

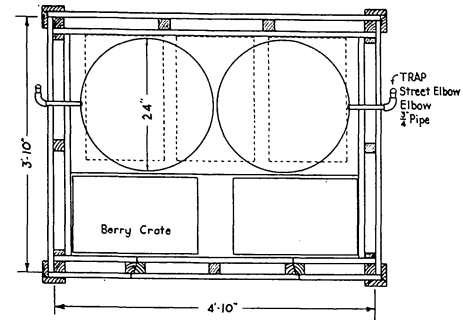
CONSTRUCTION AND OPERATION OF AN ICE REFRIGERATOR

The construction of an ice refrigerator suitable for cooling berries on the farm is neither difficult nor expensive. Figure 15 shows details of construction for a refrigerator similar to the one built for experimental purposes at the Fruit Breeding Farm in 1934. The capacity of this refrigerator is thirty-eight 24-pint Hallock raspberry crates, or twenty-two 24-quart Hallock strawberry crates. The cost of materials is approximately $35 which represents an annual cost, including all charges, of only $4.55 for a period of 10 years. Two used, 50-gallon, steel drums, originally containing lime sulphur solution, were used for the ice chamber, and no cost is charged for these drums, as fruit growers frequently have available discarded drums of this type. Two such steel drums easily hold 400 pounds of ice. The drain pipes should not allow water to stand in the drums, but should be arranged in such a way as to prevent the entrance of air. A shallow, galvanized steel drip-pan, not more than one inch deep, must be provided to catch any condensation from the drums. The bottom of the drip-pan should be insulated with standard insulation board and waterproof paper, to prevent condensation on the bottom of the pan.

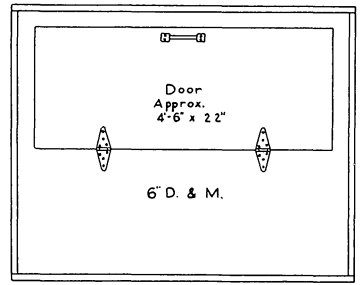
An ice chamber of the bunker type might be substituted. This would increase the expense to some extent, especially if steel drums are available without additional cost. If a bunker type of construction is used, there should be an opening for air circulation at both the top and the bottom of the ice bunker. The size of each opening should be 90 square inches per 100 pounds of ice capacity. The size of the ice chamber should be about 30 per cent of the total available space. For ordinary loading, each cubic foot of ice chamber will hold about 50 pounds of ice. If a fan is installed, the ice capacity may be reduced.

It is particularly important, when building a refrigerator, to avoid materials that will produce an odor. Spruce is generally used in household refrigerators. Douglas fir is satisfactory and is less expensive and more easily obtainable than spruce. Cedar should not be used because of the objectionable odor it imparts to the berries. Pitch pockets should be carefully avoided.

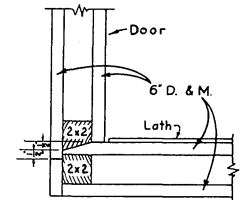
Different materials may be used for insulation. It is not necessary to provide as much insulation as would be desirable if the refrigerator were to be in use throughout the year. In the experimental refrigerator constructed, the insulation consisted of about two inches of rock-wool bat, placed between the studding and joists, which were made of 2×2-inch lumber.



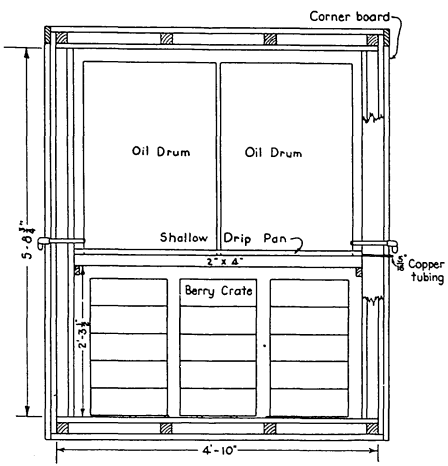
TOP SECTION



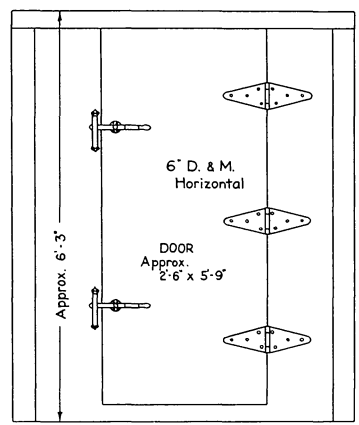
TOP VIEW



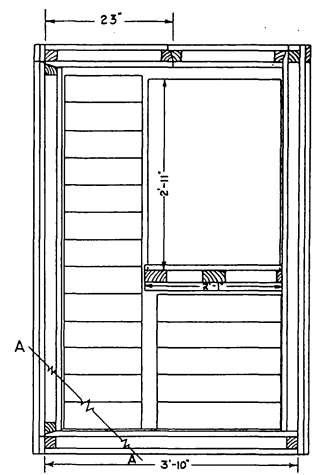
DETAIL
SECTION A-A



FRONT SECTION



FRONT VIEW



SIDE SECTION

Fig. 15. Plan for a Simple Farm Refrigerator for Cooling Berries

It is very important to prevent, as far as possible, the adsorption of moisture by the material used for insulation. A slight increase in moisture adds materially to conductivity. When the temperature of a room is lowered, the pressure of the air is reduced, and that induces air infiltration. The air, passing through walls, condenses some of its moisture upon contact with the cooler portions at or below the dewpoint. This moisture is deposited toward the low temperature side. Therefore, the more air-proof the construction, the more effective the insulation will remain.

Materials Used

	Approximate cost
Insulation	
120 sq. ft. of 2-inch insulation between studding and joists	
12 sq. ft. ½-inch insulation board	
300 sq. ft. waterproof insulation paper	
	$ 8.00
Lumber	
Six 2x2x 8 No. 1 fir S4S	
Two 2x2x10 " " " "	
Ten 2x2x12 " " " "	
One 2x4x 8 No. 2 fir S4S	
One 2x4x10 " " " "	
Eight 1x4x12 No. 2 pine S4S	
350 ft. 1x6 D and M No. 2 fir	
Eight 4-foot laths	
	19.00
Hardware and pipe fittings	
1½ pair 8-inch strap hinges	
1 pair 6-inch " "	
1 door pull	
8 lb. 6d box nails	
3 lb. 7d " "	
1 drip-pan galvanized	
2 ft. ¾-inch galvanized pipe with threads	
Two ¾-inch elbows	
Two ¾-inch street elbows	
1 ft. 5/16 copper pipe and union	
	4.00
Paint, varnish, and shellac	4.00
	$35.00

Two special refrigerator door fasteners may be added at a cost of about one dollar each. No cost is shown for two used 50-gallon steel drums.

The use of waterproof paper on both sides of the studding and joists is recommended. This should be standard insulating paper, which is odorless. Such paper may be obtained from any company handling insulating materials. Hot asphalt applied to both sides of

any of the standard insulating boards provides better moisture resistance, but adds to the expense, and has not been included in the estimate of cost. One gallon of odorless asphalt, of the type used for refrigeration, will cover about 14 square feet with two coats, at a cost for material of about five cents a square foot.

The doors are made last, to fit the openings. The two vertical long pieces are beveled to fit easily into the opening and the crosspieces are cut to fit between them. The 2×2-inch framing is next nailed up and a middle piece put in vertically for the front door. The matched lumber is nailed on the inside of the door, just even with the "2×2." The insulation is then applied, and the outside boards are nailed securely in place. These project past the frame half an inch all around. As the doors are subject to hard usage, they should be well made. The refrigerator fasteners shown in Figure 15 will hold the large door tightly closed.

The inside of the refrigerator should be finished by applying varnish over two coats of shellac. The shellac prevents excessive penetration of varnish and adds to the moisture resistance. In place of shellac and varnish, a good enamel paint may be used over two coats of aluminum paint applied as priming.

Amount of Ice Required

The amount of ice necessary to cool a given amount of fruit depends on the initial and final temperature of the fruit, its specific heat, and the heat of respiration. Without considering the heat of respiration, which may be balanced by a relatively small amount of ice, the following formula will determine the number of pounds of ice required:

$$\frac{\text{Pounds of fruit} \times 0.9 \text{ (specific heat of fruit)} \times \text{degrees F. fruit is cooled}^{6}}{144 \text{ (B.t.u. required to melt one lb. ice)}}$$

It requires about four pounds of ice to cool one crate of raspberries 30 degrees F.

To this must be added the amount of ice required to balance the heat conduction through the walls of the refrigerator. The conductivity of many types of construction and of various insulating materials is given by Fogle (5) in data provided by the United States Bureau of Standards. The amount of ice required to offset this conduction may be determined in the following manner. First, the conductivity of the wall is determined by consulting any standard table showing the conductivity of the various building materials. The customary measure of this conductivity is the amount of heat in B.t.u. that will pass in one

[6] The specific heat is the quantity of heat in B.t.u. that must be extracted to cool one pound one degree F. B.t.u. denotes British thermal unit and one unit is the amount of heat required to heat one pound of water one degree F.

hour through one square foot of the material one inch in thickness, with a temperature difference of one degree F. between the inside and the outside surfaces. The ice-melting equivalent of the conduction through the refrigerator wall is, therefore:

$$\frac{\text{Conductivity of wall in B.t.u.} \times 24}{144} = \text{ice-melting equivalent per square foot per day.}$$

The total amount of ice needed to offset conduction through the walls is determined by multiplying the ice-melting equivalent per square foot per day by the number of square feet in the outside wall, and multiplying again by the difference in temperature Fahrenheit between the outside air and the temperature inside the refrigerator.

The type of construction recommended, using about two inches of insulation between the studding and joists, has a conductivity of .092 B.t.u. per square foot per degree temperature difference per hour. The ice-melting equivalent per day is determined by multiplying .092 by 24 and dividing by 144 (the number of B.t.u. required to melt one pound of ice). This gives a heat conduction per day of .015 pound of ice-melting effort per square foot per degree. The refrigerator shown in Figure 16 has an outside surface of approximately 150 square feet. The number of pounds of ice required for an average temperature difference of 30 degrees F. therefore would be 150 × 30 × .015, or 67.5 pounds per day. This makes no allowance for heat loss, caused by opening of the door. A canvas curtain dropped across the door from the inside will reduce this loss to a minimum.

The ice consumption of the refrigerator at the Fruit Breeding Farm in 1934 averaged 86 pounds per day, for a period of six weeks, but only relatively small quantities of fruit were cooled during that period. An average of 15 to 20 crates of raspberries cooled per day would require about 150 pounds of ice daily.

It is essential to have the ice chamber well filled when warm fruit is being cooled, but after cooling has been accomplished the temperature desired may be maintained with less ice. Newell and Lloyd (16) show that in well-built refrigerator cars, with bunkers of about 10,000 pounds capacity, the ice supply can fall well below half the maximum capacity of the bunkers without allowing an increase in fruit temperatures, if the fruit has been thoroly cooled.

The actual amount of ice required to offset the heat produced by respiration is difficult to figure accurately. According to Rose *et al.* (22), the heat of respiration produced by Howard 17 strawberries in cooling from 80 to 35 degrees F. in three days amounts to 38,000 B.t.u. per ton of fruit, which is sufficient to melt about 264 pounds of ice. This would be equivalent to about 1¼ pounds of ice per crate of strawberries per day. The heat of respiration varies according to the tem-

perature of the fruit, as shown by Gore (7), and there may be from 25 to 30 per cent difference in the heat of respiration between different varieties of strawberries, according to Haller *et al.* (8).

Use of Salt

There appears to be no advantage from the use of salt in the ice chamber for cooling berries that are to be marketed within relatively short distances. Should long-distance shipments be necessary, a more rapid cooling undoubtedly would be desirable. Galloway (6) makes the following recommendations on the basis of experiments conducted with strawberries and peaches:

Loading temperature	60 degrees F. or lower	3 per cent salt
" "	60 to 75 degrees F.	5 " " "
" "	75 degrees F. or higher	7 " " "

Lloyd and Newell (13) show that precautions taken to insure the fruit's being as cool as possible when placed under refrigeration are of greater benefit in car-lot fruit transportation than any amount of salt that can safely be added to the bunker ice.

RECOMMENDATIONS

1. Growers should supervise their pickers closely to see that the berries at all times are picked and handled very carefully.

2. Berries that are over-ripe or injured should be placed by the pickers in separate boxes.

3. Picking in the middle of the day during hot weather should be avoided, if possible. In these experiments berries picked in the early morning or late afternoon kept better than those picked at midday. Berries that are picked in the middle of the day should reach the consumer without undue delay.

4. Berries, as soon as picked, should be placed in a well-ventilated berry shed or other place that is open on all sides to permit a maximum of air movement.

5. The cooling of berries by ice refrigeration on the farm will prolong the marketable condition for several days. A suitable refrigerator can be built at low cost. The construction and use of such a refrigerator is recommended for growers who normally lose some berries from spoilage or who are forced at times to sell their berries at a low price to escape loss from spoilage.

6. Berries to be cooled by ice refrigeration may be placed first in a well-ventilated berry shed for about two hours without any apparent loss of keeping-quality. It is obvious that this practice will result in a saving of ice, and it seems likely that the evaporation which takes

place in the berry shed may improve the keeping-quality when the moisture content of the berry is high, altho no studies of this phase of the problem were made.

7. A ventilated type of crate, with wood-veneer boxes, is the most satisfactory for raspberries.

SUMMARY

The principal factors that determine the condition of berries on the market are (a) firmness of the variety, (b) freedom of the fruit from injuries, (c) maturity at the time of picking, (d) weather conditions during the ripening period, and (e) temperature of the berries after picking.

No appreciable difference was found in the keeping-quality of the Chief and Latham raspberries, except that Chief retains a brighter appearance, and is, therefore, in better marketable condition after an equal period of storage.

Raspberries picked at the same time, but by different pickers, showed a wide variation in the subsequent rate of decay. Strawberries injured in the field by insects or by birds prior to picking decayed much more rapidly than similar berries injured at the time of picking.

Raspberries picked in the early morning and in the late afternoon remained longer in marketable condition than similar berries picked in the middle of the day, when not cooled by refrigeration or when cooled for relatively short periods. There was no appreciable difference in the keeping quality of raspberries picked at different hours of the day, when the berries were held for six days in a refrigerator.

The temperature of freshly picked raspberries is above that of the surrounding air, except in the early morning. The berries, after being picked and placed in the shade, cool to several degrees below the air temperature. This cooling takes place rapidly when the berries are exposed to wind, and their temperature becomes stationary after about two hours. During this period they cool as rapidly or more rapidly than when placed in a refrigerator not equipped with a fan. Where there is little or no air movement, the berries cool slowly, their temperature becoming stationary after about four hours. On a warm day raspberries picked in the early morning remain very much cooler during the day than those picked later.

Raspberries placed in an enclosed building with windows and doors open cool more slowly than those placed in a well-ventilated berry shed consisting only of a roof and partial protection on the south side. Freshly picked raspberries usually cool more rapidly at first in such a berry shed than in a cool cellar or than on the ground in the shade of a berry bush.

Raspberries in the bottom deck of a ventilated Hallock-type crate cool much more rapidly than those in an old-style non-ventilated crate of the same type. Raspberries in wood-veneer pint boxes cool more rapidly than those in paperboard pint containers.

A farm refrigerator suitable for the cooling of berries can be constructed and operated at a very moderate cost. Materials for the construction of a refrigerator holding thirty-eight 24-pint crates can be purchased for about $35. The quantity of ice required will vary according to the number of crates cooled, the temperature of the berries, and the outside temperature. An average of 15 to 20 raspberry crates cooled per day would require about 150 pounds of ice daily. A refrigerator of this type will hold raspberries in marketable condition from five to seven days, and strawberries may be held in marketable condition for a longer period.

A few hours' delay in placing raspberries in a refrigerator had no appreciable effect on the length of time the berries remained in marketable condition, but berries picked in the early morning and not cooled until the afternoon or evening of the same day showed a decided loss in keeping-quality.

After the first 24 hours of refrigeration, the longer berries remain in a refrigerator the shorter will be the time they remain in marketable condition after they are taken out of the refrigerator. Under the conditions of these experiments, the maximum was 59 hours in marketable condition after 24 hours of refrigeration, and the minimum was 8 hours after 7 days of refrigeration.

The rate of cooling of berries in a refrigerator will vary according to the quantity of fruit and the capacity of the refrigerator. With small quantities of fruit and a fan in operation, the rate of cooling averaged 15 to 20 degrees F. for the first hour and from 2 to 8 degrees F. per hour thereafter. Without a fan, the rate of cooling averaged 4 to 6 degrees F. per hour. Large quantities of fruit retard the rate of cooling. With a capacity load of 446 crates, and a fan in operation, the rate of cooling averaged 5 degrees F. per hour.

LITERATURE CITED

1. Alderman, W. H., Winter, J. D., and Cox, Rex W. Raspberry and strawberry production trends in Minnesota. Minn. Agr. Exp. Sta. Bul. 305. 1934.
2. Appleman, C. A., and Conrad, C. M. Pectic constituents of peaches and their relation to softening of fruit. Md. Agr. Exp. Sta. Bul. 283, p. 6. 1926.
3. Brooks, Charles. Spoilage of stone fruits on the market. U. S. D. A. Circ. 253. 1933.
4. Darrow, G. M. Strawberry culture: eastern United States. U. S. D. A. Farmers Bul. 1028. 1919.

5. Fogle, F. E. Insulating value of building materials. Mich. Quart. Bul. 10 (No. 3) :97-104. 1928.
6. Galloway, A. G. A portable precooling apparatus. U. S. D. A. Bur. Plant Indus. (Mimeographed) 1929.
7. Gore, H. C. Studies on fruit respiration. U.S.D.A. Bur. Chem. Bul. 142. 1911.
8. Haller, M. H., Harding, P. L., Lutz, J. M., and Rose, D. H. The respiration of some fruits in relation to temperature. Amer. Soc. Hort. Sci. Proc. (1931) **28**:583-89. 1932.
9. Hartman, Henry, Magness, J. R., Reimer, F. C., and Haller, M. H. Investigations on the harvesting and handling of Bosc pears from the Rouge River Valley. Oreg. Agr. Exp. Sta. Bul. 228, p. 12. 1927.
10. ————, Reimer, F. C., and Norris, R. K. Further investigations on the harvesting, storing, and ripening of pears from the Rouge River Valley. Oreg. Agr. Exp. Sta. Bul. 254, p. 10. 1929.
11. Hawkins, L. A., and Sando, C. E. Effect of temperature on the resistance to wounding of certain small fruits and cherries. U.S.D.A. Bul. 830. 1920.
12. Kimbrough, W. D. The quality of strawberries as influenced by rainfall, soil moisture, and fertilizer treatments. Amer. Soc. Hort. Sci. Proc. (1930) **27**:184-86. 1931.
13. Lloyd, J. W., and Newell, H. M. Observations on the refrigeration of some Illinois fruits in transit. Ill. Agr. Exp. Sta. Bul. 334. 1929.
14. ————. Some factors influencing the keeping quality of fruit in transit. Ill. Agr. Exp. Sta. Bul. 350. 1930.
15. Magness, J. R., Haller, M. H., and Graham, W. S. The ripening, storage, and handling of apples. U. S. D. A. Bul. 1406. 1926.
16. Newell, H. M., and Lloyd, J. W. Air circulation and temperature conditions in refrigerated carloads of fruit. Ill. Agr. Exp. Sta. Bul. 381. 1932.
17. Overholser, E. L. Cold storage versus room temperatures on keeping qualities of fruits. Science **66**:660-61. 1927.
18. ———— and Moses, B. D. Precooling of fresh fruits and temperatures of refrigerator cars and warehouse rooms. Calif. Agr. Exp. Sta. Bul. 496. 1930.
19. Platenius, H., Jamison, F. S., and Thompson, H. C. Studies on cold storage of vegetables. Cornell Univ. Agr. Exp. Sta. Bul. 602. 1934.
20. Ramsey, H. J. Factors governing the successful shipment of red raspberries from the Puyallup Valley. U. S. D. A. Bul. 274. 1924. (Revised)
21. Rendle, T. Observations on changes in raspberries after picking. Analyst **58** (No. 683) : 69-77. 1933.
22. Rose, Dean H., Wright, R. C., and Whiteman, T. M. The commercial storage of fruits, vegetables, and florists stocks. U. S. D. A. Circ. 278. 1934. (Revised)
23. Stevens, Neil E. Keeping quality of strawberries in relation to their temperatures when picked. Phytopath. **9** (No. 4) : 171-77. 1919.
24. ————. A method of testing the keeping quality of certain small fruits. Phytopath. **19** (No. 6) : 593-96. 1929.
25. ———— and Wilcox, R. B. The temperatures of small fruits when picked. Plant World **21**:176-83. July 1918.
26. Tavernetti, James R. Construction and operation of mechanical refrigerators for farms. Calif. Agr. Exp. Sta. Circ. 329. 1933.