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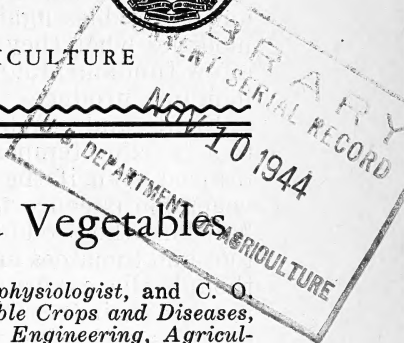
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Freezing Injury of Fruits and Vegetables

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IN THE HANDLING, STORAGE, AND TRANSPORTATION of fresh fruits and vegetables, it frequently becomes necessary to protect them against freezing or to care for them and determine whether they are usable after they have frozen. How to deal with both of these problems is of importance to a great many people, including officials of the Army and Navy responsible for perishable produce destined for the armed forces, market inspectors, employees of railroad and truck companies, market receivers and distributors, and cold-storage operators. It seems desirable, therefore, to summarize the information now available on the subject, in order to keep preventable loss and damage to a minimum and so help to conserve food materials that are so essential to the war effort. This circular presents the results of observations on the market and of experimental investigations at controlled temperatures 7° to 18° F. below the freezing point of water.

SEVERITY OF INJURY DEPENDENT ON TEMPERATURE AND ITS DURATION

Problems that arise in connection with the protection of fruits and vegetables against freezing and with the care of these commodities when they have frozen can be solved more intelligently if a few fundamental principles are understood and used as guides in handling produce.

Fruits and vegetables do not freeze immediately when exposed to a freezing temperature, and many of them are not immediately injured even if they do freeze. Much depends on what fruit or vegetable is concerned, on how low the temperature goes, and on how long the product is exposed to the dangerous condition. Potatoes and tomatoes are injured if any ice forms in their tissues even though the exposure is very brief and the temperature barely reaches their freezing points. In this respect they resemble sweetpotatoes and other products listed on page 30 in the group most susceptible to cold or freezing injury.

On the other hand, apples, cabbage, carrots, and other produce in the groups moderately susceptible or least susceptible to freezing injury (p. 30) are injured very little by exposure to temperatures only a few degrees below their freezing points, whereas at temperatures below about 20° F. they are in much greater danger. However, if these two different sets of conditions are assumed, the time element becomes of the utmost importance. Apples exposed to 25°, say for only a few hours, will be damaged very little if at all, whereas if they remain at that temperature for 3 or 4 days they may be so softened and otherwise injured that their keeping quality is seriously impaired. At 15° to 18°, however, they may be damaged as much in 12 to 15 hours as they would be at 25° to 27° in 3 or 4 days. If held at the lower temperature (15° to 18°) for several days, they become "frozen to death" and worthless. Similar statements are true for numerous other products in the moderately and least susceptible groups.

The important fact in the preceding discussion is that for any given product the combination of time and temperature determines the severity of injury. Enough time must elapse for the *formation of ice* in the tissues; and, for reasons that are not well understood, enough more time must elapse so that the tissues suffer injury from which they cannot recover. The lower the temperature the shorter the dangerous, critical period. The length of this period varies with different products, but its significance and importance should always be kept in mind.

METHODS OF PROTECTING FRESH FRUITS AND VEGETABLES AGAINST FREEZING

Methods of protecting fresh fruits and vegetables while in cold storage or on the way to market are fairly well known, although they are not always used intelligently or with full appreciation of the risks involved if they are not used.

Sometimes these perishable products are held in storage at too low temperatures or in rooms where the temperature occasionally

falls below their freezing points; sometimes they are loaded into cars or truck without adequate protection from low outside temperatures during the loading process; in still other instances they are transported in cars where heater service is not furnished at the proper time or in the necessary amount; or they are hauled to market in trucks with little or no protection except that furnished by the containers. In all such instances the use of foresight and care will do much to prevent damage from freezing. In cold weather the transportation of fruits and vegetables by truck can be made safer by placing straw, hay, or paper around the inside of the truck body and tarpaulins over the top of the load. Under extreme conditions it may be advisable not to attempt long-distance transportation of these commodities by truck.

If a carload of produce showing signs of freezing arrives on the market there are several possible ways in which it may be handled, although the receiver may not always be free to choose the one he will use. In many instances he can do nothing but unload the car and put the produce into trade channels. On the other hand, he may be able to leave it in the car to thaw out either because of moderate outside temperatures in the local area or by the use of heaters placed in the car. As a third choice, he may unload the produce and take it to a pier, warehouse, or store and leave it to thaw slowly.

A temperature of about 40° F. has been found most satisfactory for the thawing of apples, onions, and potatoes, and probably it would be desirable for other fruits and vegetables. Too high temperature—60° to 70°, for example—will favor decay and may bring about yellowing or withering of vegetables and too rapid ripening of fruits if the produce is left at such temperatures for several days. If packages have to be handled in order to put them in a place where the produce will thaw, they should be stacked in such a way as to permit free circulation of air around them. In the experimental work discussed on pages 5 to 25 and partially summarized in table 1, thawing temperatures of 45° and 60° were frequently used in order to determine within a relatively short time how much and what kind of deterioration occurs in products that have frozen. There is no intent to imply that the thawing temperatures shown in column 9 of table 1 are the optimum for the different commodities.

Whatever method is used in caring for a shipment, it should always be remembered that produce should not be handled while frozen if such handling can possibly be avoided; the reason for this is that when fruits or vegetables are in a frozen condition the effect of even slight bruising extends deep into the flesh and much more damage results than from similar bruising of unfrozen products. Leafy vegetables when frozen are easily broken and mashed by being handled.

If fruits or vegetables have to be hauled to a pier, warehouse, or store in freezing weather, they should be protected by means of paper, hay, or straw around the inside of the truck body and tarpaulins over the top. Individual packages in small lots, if hauled to stores in unheated trucks in freezing weather, can be protected by wrapping them in heavy paper.

If the shipments arrive at market in good condition but, after being unloaded, have to be held on a pier or in a receiver's warehouse or storeroom during severely cold weather, the danger that they may freeze depends on (1) the quantity of the fruits or vegetables to be stored and their temperature before exposure to the conditions where they must be held, (2) the amount of artificial heat provided, (3) the tightness and insulating quality of the pier or warehouse construction, (4) the temperature of the storage space during the previous day, and (5) the quantity of other commodities held in the storage space and their capacity for retaining heat.

Additional facts that should be kept in mind in attempting to prevent freezing are (1) produce cools more slowly if packed tightly than if packed loosely and more slowly in tight boxes, baskets, or barrels than in slatted crates or hampers; (2) certain produce (pears, apples, and citrus fruits) cools more slowly if wrapped than if not wrapped; (3) close stacking of packages gives some protection from freezing; (4) the bottoms of outside stacks need the most protection because freezing occurs there first; (5) sawdust along the bottoms of outside doors helps to keep cold air out; (6) a covering, such as a tarpaulin, over the stacks and tucked carefully around them, especially at the bottom, helps to retain both the heat already present in the produce and that which it produces by virtue of being alive (heat of respiration).

Even if there is no permanent equipment for heating the room or pier, substantial help in keeping up the air temperature can be obtained by setting barrels, oil drums, or buckets of hot water under the tarpaulins where heat is most likely to be needed. Since water will freeze before any of the fruits or vegetables do, the heat it gives up on freezing is available for further protection. The heat that could be furnished by a lighted lantern, an oil heater, or a container full of hot water set under a tarpaulin covering stacks of produce might seem small, but it might be just enough to keep the produce from freezing. The beginning of ice formation on water in a container can be taken as a sign that the surrounding temperature is becoming dangerously low. It should be remembered, however, that the heat given up by the water as it freezes can help to protect the produce until all the water is turned to ice. Care should be taken, of course, that overheating does not occur.

LENGTH OF TIME REQUIRED FOR FREEZING TO OCCUR

Because of qualifying factors already mentioned (p. 4) it is not safe to make general statements concerning the time required for fruits and vegetables to freeze in a place where the air temperature is below 32° F. Even if surrounding conditions were identical there might still be differences in freezing time, because of differences in varieties or kinds, in maturity of the commodity, and in its freshness. Freshness would be important chiefly in connection with leafy crops such as spinach, lettuce, and kale.

In order to obtain information on freezing under specific conditions, single commercial packages of 4 kinds of fruit and 23 kinds of vegetables were held at 14° to 25° F. until freezing occurred in

at least the most exposed parts of the pack. The length of exposure varied from 3 or 4 hours to several days. Details of the tests are given in table 1. Brief descriptions of the symptoms of freezing injury in the various commodities appear in the text. In many instances statements about freezing injury in the particular commodity as observed on the market are also given. Information as to the temperature of the produce at different positions in the package was obtained by means of thermocouples and a potentiometer. The thermocouples were thrust into the produce to a depth of 1 or 2 inches; hence they did not show the temperature at the surface. Statements concerning the time of the first occurrence of freezing of each commodity are usually based on evidence obtained by visual and manual examinations.

The wraps used for apples, grapefruit, lemons, and oranges were of the kind commonly used for these fruits in commercial operations.

In these tests it was possible to determine within rather narrow limits the time when freezing occurred in a given commodity, especially in the more exposed parts of the package. It should be clearly understood, however, that the periods given in table 1, columns 6 and 7, are to be accepted as only approximate if it is desired to apply them in the handling of other packs and kinds of packages of the same commodities under various commercial conditions.

APPLES

EXPERIMENTAL OBSERVATIONS

Apples in two eastern boxes were held in an 18° F. room for 51 hours; those in one box were individually wrapped and those in the other were not wrapped. The boxes were not papered over the outside, but both were lidded. (For rate of cooling of these two lots see figure 1.) When the fruits were examined immediately after removal from the freezing room, freezing was found to extend to the center of both boxes.

After a week at 31° F. it was found that the severest injury was in the unwrapped lot. The apples in that lot showed numerous water-soaked bruises, with browning underneath, extending deep into the flesh, and the flesh was generally dry and mealy. The bruises occurred where the apples had touched each other or the box, although they were not under pressure from the lid. Some of these bruises were similar to those that can be produced by jolting apples under pressure; others extended so deep and the flesh was so much browned that the injury could have been caused only by freezing. A few fruits in this box were brown throughout, mushy, and clearly frozen to death. The same symptoms, to a much smaller degree, occurred in the wrapped apples, except that none were brown throughout, watery, or mushy.

Apples in two unpapered eastern boxes were held in a 21° to 24° F. room for 54 hours. Those in one box were individually wrapped and those in the other were not wrapped. On removal from the freezing room, fruits were found frozen in all parts of both boxes but not all fruits were frozen. When the fruits were cut, bruising

TABLE 1.—Freezing injury of fruits and vegetables

Commodity	Kind of package	Extra protection	Approximate temperature of commodity at start	Temperature of freezing room	Approximate period before freezing began		Length of time in freezing room	Thawing temperature	Degree of injury
					At top and sides	At center			
Apples	Box, not papered	Fruits wrapped	33	18	Hours 3-4	Hours 24	Hours 51	°F. 31	Severe.
Do.	do.	Fruits not wrapped	31	18	3	7-8	51	31	Do.
Do.	do.	Fruits wrapped	31	21-24	36	44-48	54	31	Moderate.
Do.	do.	Fruits not wrapped	31	21-24	12-14	20-24	54	31	Do.
Grapefruit	Crate, not papered	Fruits wrapped	32	18	2	7	25	45	Slight.
Do.	do.	Fruits not wrapped	32	18	2	7	25	45	Do.
Lemons	do.	Fruits wrapped	32	18	3	24	75	45	Severe.
Do.	do.	Fruits not wrapped	32	18	3	7-8	75	45	Do.
Oranges	do.	Fruits wrapped	32	18	2	24	25	45	Do.
Do.	do.	Fruits not wrapped	32	18	2	7	25	45	Do.
Asparagus	Crate	Paper	34	20	3	(²)	24	60	Do.
Beans	do.	do.	33	24	7	(³)	7	45	Moderate.
Lima	1/2-bushel hamper	do.	32	18	41-6	48	48	45	Severe.
Do.	Bushel hamper	do.	34	24	7	(³)	7	45	Moderate.
Snap	do.	do.	62	24	24-28	(³)	28	60	Slight.
Beets, bunch	Crate	do.	32	24	4-5	7	30	60	Do.
Do.	do.	do.	45	24	22	22	72	55	Moderate.
Broccoli, sprouting	do.	do.	64	25	7	(³)	48	45	Slight.
Cabbage	Bushel basket	None	36	25	1	24	30	45	Do.
Do.	do.	do.	33	24	3	4	78	60	Do.
Do.	Crate	do.	53	18	8	10	24	45	Do.
Carrots	do.	do.	35	20	1-2	(³)	48	45	Slight.
Not topped	Crate	Paper outside	32	18 and 14	43-4	6	45	60	Severe.
Topped	do.	Paper inside	35	20	1	(³)	31	60	Very slight.
Cauliflower	do.	Paper	32	20	2	6-7	7	60	Severe.
Celery	do.	do.	45	20	49	26	72	55	Do.
Bianched	do.	do.	32	18	7	120	120	45	Do.
Pascal, unblanched	Bushel basket	do.	35	24	7	48	48	60	Severe.
Corn, green	1/2-bushel basket	do.	32	18	3	3	78	45	None.
Cucumbers	Bushel basket	do.	32	24	5	(³)	60	60	None.
Do.	do.	None	35	24	5	(³)	72	60	Slight.
Eggplant	Crate	Paper	32	20	5	(³)	60	60	Do.
Lettuce	do.	do.	31	21-24	4-5	6-7	54	31	Moderate.
Onions	Bag	None	31	24	4-5	6-7	54	31	Do.
Parsnips	Base in a box	do.	50	24	24-28	28	28	60	None.
Do.	1/2-bushel hamper	Paper	32	24	4-5	7	30	60	Do.
Do.	do.	do.	35	24	7	12-15	50	60	Do. ⁴
Peas	Bushel hamper	do.	33	24	2	6	24	60	Moderate.
Peppers	Bushel basket	do.	36	25	2	2	29	45	Slight.
Rutabagas	Bushel bag	None	64	25	18-20	31	31	45	Do.
Do.	do.	do.	57	18	7	7	24	45	Do.

Spinach.....													
Squashes:													
Acorn.....	Bushel basket.....	Paper.....	35	24	20-27	(3)	96	40	Very slight.				
Blue Hubbard.....	$\frac{5}{8}$ -bushel hamper.....	do.....	34	24	19-21	(2)	144	60	Severe.				
Summer (Yellow Crookneck).....	None.....	None.....	35	24	(2)	(2)	144	60	Moderate.				
Sweetpotatoes.....	Bushel basket.....	Paper.....	37	24	6-6	24	24	60	Severe.				
Do.....	$\frac{5}{8}$ -bushel hamper.....	None.....	31	18	1	4-5	51	45	Do.				
Tomatoes.....	None.....	do.....	50	22	3	(2)	3-4	60	Do.				
Turnips.....	30-pound lug.....	do.....	50	18	7	(2)	48	45	Do.				
	Bushel basket.....	Paper.....	33	24	19-21	(2)	144	60	Do.				

¹ As determined from temperature records and from observation of the products while in the freezing room.

² No record obtained.

³ No freezing occurred during the experiment.

⁴ See text.

⁵ Pad under lid; crate lined.

⁶ At 18° F.

⁷ At 14° F.

⁸ Eastern crate (2 dozen heads).

⁹ Few after 48 hours.

was more noticeable in those that were frozen than in those that were not but it was only slight even in the frozen fruits. After a week at 31° neither the wrapped nor the unwrapped lot showed any change from the condition found when the fruit was removed from the freezing room.

MARKET OBSERVATIONS ¹

Many persons think that the presence of ice in an apple is *prima facie* evidence of freezing injury. Theoretically they are right; practically they may not be. The confusion is due to a failure to distinguish between slight freezing and freezing to death in which enough ice is formed to cause permanent and visible injury. Doubtless the least incipient ice formation injures the apple flesh to some degree, but so far as present knowledge goes there is no visible evidence of injury by such slight freezing and no effect upon the market value of the fruit. If, however, the freezing process is carried somewhat further, a slight noticeable injury results, even though the cells may appear practically normal; if freezing is carried still further, the cells may be killed, in which event they turn brown. Regardless of how much ice appears in the fruit it is inaccurate to say that the apple shows freezing injury unless a significant proportion of the cells show this browning.

EXTERNAL AND INTERNAL APPEARANCE OF FROZEN APPLES

If freezing of an apple has been slight, there may be no marked external symptoms of any sort; if it has been severe, the general outside appearance is strikingly affected. The surface is discolored in irregularly shaped areas—becomes so, in fact, very soon after the apple thaws—and appears considerably darkened. It often assumes a water-soaked, brown color closely resembling that of apple scald, or the color may become much darker, in some cases almost black. When apples are in a frozen condition the skin becomes slightly shriveled, but the shriveling usually occurs in the form of a network of wrinkles rather than as parallel lines of shrinkage such as are produced by normal evaporation. Careful measurements have shown also that the fruit actually becomes smaller, sometimes by as much as 10 percent of its original volume. On thawing it regains practically its original volume unless the freezing was very severe.

When apples thaw after having been badly frozen the skin becomes shriveled, particularly if the air in the storage place is very dry. This form of shriveling seems to be due to rapid evaporation, after thawing, of the water withdrawn from the cells and changed into ice in the spaces between the cells during the freezing process. Shriveling when slight is accompanied by a reduction chiefly in size and when severe by a marked reduction in both size and weight.

Apples that have been severely frozen frequently show noticeably sunken spots, which may be a quarter of an inch or more deep

¹ Adapted from ROSE, D. H., BROOKS, C., FISHER, D. F., and BRATLEY, C. O. MARKET DISEASES OF FRUITS AND VEGETABLES: APPLES, PEARS, QUINCES. U. S. Dept. Agr. Misc. Pub. 168, 71 pp., illus. 1933. (See pp. 16, 17, 26-29.)

and have a superficial diameter about equal to their depth. In virtually all cases these sunken spots develop at places that were bruised while the apples were still frozen.

When freezing occurs the cells of the vascular, or water-conducting, system are usually the first to be affected, especially if the freezing takes place rapidly; and they may be the only ones so affected. In cross section this injury is shown by a brown discoloration of the 10 large main water-conducting bundles, the color being visible evidence that the cells have been frozen to death. Similar browning may occur in the smaller strands through the flesh and in the core tissue; it is frequently restricted to one side of the apple because of lower temperature on that side. In more extreme cases all the tissues may be affected; the flesh then shows a solid color throughout, which varies from bright golden brown to darker brown or almost black, depending on the variety of apple and the severity and freshness of the freezing injury. These browned areas in whatever tissue found usually have a water-soaked appearance and in milder injury are translucent.

It should be remembered, however, that during a short exposure to an air temperature several degrees below freezing considerable ice may form within the tissues and yet produce little or no effect that could be diagnosed as freezing injury.

FREEZING INJURY AND TRANSIT BRUISING

Apples that have been both bruised and frozen while in transit by rail frequently show flattened areas $1\frac{1}{2}$ to 2 inches in diameter that are somewhat sunken and soft toward the center and have a dull-brown or slate color over most or all of the surface.

Another kind of bruising occurs in boxed apples in transit. This injury is usually found only in apples at the lower side of the bottom layer of boxes in the car and for this reason is frequently attributed to freezing. It is more common during winter than during fall and spring, but nevertheless it has been found in boxed apples shipped in the fall before freezing weather has occurred in the producing districts or anywhere along the route taken by the shipment. The injury has also been found so late in the spring that there was no possibility of the fruit having been exposed to freezing weather in transit.

This transit bruising is characterized by flat, bruised areas on the sides of the apples that were in contact with the lower side of the box as the latter lay in the car. These areas have a water-soaked, darkened appearance, are generally rather firm, and may be an inch or more in diameter. Occasionally the skin covering them is discolored in spots or streaks. In cross section there is usually a water-soaked, glassy, wedge-shaped area extending from the skin toward the center of the apple. It may be shallow or may extend quite to the core. In some instances the inner edge of this area appears as a fairly smooth curve, convex toward the core; in others it is broken by strands or rays having the water-soaked appearance just mentioned and extending radially for as much as three-quarters of an inch beyond the main affected area. Small, water-soaked patches or streaks are sometimes seen also under-

neath bruises produced by the pressure of one apple against another.

Bruises like those just described can be produced by subjecting apples to a jolting similar to that received while they are in transit by rail. Glassy, water-soaked bruises are not necessarily a sign of freezing injury; neither are wedge-shaped injured areas that extend to the core nor brown bruised spots under the skin, in which browning of the water-conducting bundles has occurred. All of these can be produced by the jolting and pressure that apples are subjected to while in transit in railroad cars.

EFFECT OF FREEZING AND THAWING

It is generally believed that frozen apples are injured less by gradual than by rapid thawing. Investigation has shown, however, (1) that apples frozen rapidly show an equal amount of injury when thawed at 32° and 72° F. and (2) that slowly frozen apples show more discoloration when thawed slowly (at 32°) than when thawed rapidly (at 50° or higher).

Frozen apples are often dry and mealy, probably because of loss of water through evaporation from the injured tissues. The degree of mealiness increases with the amount of freezing but is not entirely absent even when freezing is only slight. The flesh sometimes appears flaky or corky and always lacks the normal crispness; in severely frozen specimens it collapses and becomes viscid, soft, and mushy.

Apples frozen but not frozen to death may thaw out with no apparent aftereffect except a slight softening of the flesh. This softening, however, means that their prospective storage life has been shortened. The amount of the reduction will depend on the variety, the degree of maturity of the fruit when frozen, and the severity of the freezing. There is no doubt that apples that have been frozen solid throughout, even though for only a short time, will not hold up so well in storage, or for so long a time, as similar apples from the same orchard or the same storage lot or shipment that have not been frozen.

Apples should not be handled while frozen, because of the danger of serious damage from bruising. Bruises produced in this way frequently extend deep into the fruit, and the affected flesh is usually brown, soft, and somewhat watery.

FREEZING INJURY AND INTERNAL BREAK-DOWN

During January or even earlier and through the remainder of the storage season, it may sometimes be difficult to distinguish between freezing injury and internal break-down due to overripeness. The difficulty will be greatest when there is no evidence of freezing in transit. Internal break-down may be followed by browning, but the color change, unlike that which often follows freezing injury, does not begin in the main water-conducting bundles. Instead, it may begin at any place in the flesh and usually does begin at many places. In cross section, fruits affected with internal break-down often show the following symptoms: An outer shell of healthy flesh about a quarter of an inch thick sur-

rounding a brown zone which extends inward in roughly triangular patches as far as the bundles of conducting vessels or a little beyond; next to this another zone of healthy flesh; and in the flesh at the core a second area of brown.

Internal break-down is usually worse in large apples and more marked at the blossom ends than at the stem ends. Freezing injury may affect apples of any size and is not necessarily or uniformly worse at one end than at the other. Yet when one side of an apple or even the whole apple shows a uniform brown color in cross section, it will be hard to determine whether the color is due to freezing injury or internal break-down. Reliance should then be placed on all the symptoms that can be found in as many apples as can be examined conveniently rather than on any one symptom or the examination of one apple.

ASPARAGUS

Asparagus was held in a standard asparagus crate in a 20° F. room for 24 hours. The crate was papered over the sides and bottom.² After 48 hours' thawing at 60° many stalks were limp and water-soaked. Counts made on 2 bunches showed that 64 stalks, or 55 percent, had been injured by freezing. The other stalks showed no signs of freezing injury. When only part of the stalk had been injured, the affected region—the upper, tender end of the stalk — was easily detected by the limp, water-soaked, slightly shriveled condition.

LIMA BEANS

Lima beans in a bushel hamper, papered around the sides and covered with a regular hamper lid, were held in an 18° F. room for 48 hours. Freezing, recognizable by a water-soaked appearance of part or all of the pod, began in 1 hour at the top of the hamper. At the end of 6 hours pods around the sides and about 3 inches down from the top had frozen, but those in the center of the mass were not frozen. On removal from the freezing room, all pods were found frozen except those in a roughly cylindrical region about 3 inches in diameter, extending from about 4 inches below the top of the mass of beans to within about 3 inches of the bottom. After 48 hours at 45° the pods and seeds that had been frozen were limp and water-soaked.

Lima beans in a $\frac{5}{8}$ -bushel, papered hamper were held in a 24° F. room for 7 hours. At the end of that time pods at the top and next to the sides of the hamper were found slightly frozen and showed a few water-soaked spots. After 24 hours at 45° the only symptom of injury that could be detected was a slight limpness of the pods that had frozen. The seeds showed no signs of injury.

SNAP BEANS

Snap beans in a $\frac{5}{8}$ -bushel hamper, papered over the sides and bottom, were in a 24° F. room for 7 hours. After thawing for 24

² Paper was used on this crate and on packages of certain other commodities in other tests, in order to restrict air circulation and so simulate to some extent the conditions to which packages in a refrigerator car or in a stack on a pier might be subjected.

hours at 45° scattered specimens in the top 2 inches and along the sides of the hamper showed water-soaked mottling in small patches on the surface of the pods. When the injured pods were bent toward one of these patches, moisture oozed out on the surface. None of the pods appeared to have been completely frozen, and none of the beans in the center of the package showed injury of any kind. After a week longer at 60° the patches that had previously been water-soaked and discolored were dried out and turning brown.

Beans on the market that have been frozen are water-soaked and limp, and they quickly dry down or are invaded by bacteria or fungi.

BUNCH BEETS

Bunch beets in a standard crate, papered over the sides, ends, and bottom, were held in a 24° F. room for 28 hours. On removal from the freezing room the tops and roots were found frozen at the top, along the sides and ends, and at the bottom of the crate. Immediately after thawing the leaves had a water-soaked appearance. There was no freezing at the center of the crate. After 17 hours at 60° there was no sign of injury in any leaves or roots; after 12 days the small rootlets were becoming moldy, but the main roots (the beets) were still sound and firm.

On the market, freezing injury is shown by flabbiness of the roots and small radial cracks in their centers.

SPROUTING BROCCOLI

One dozen bunches, or "heads," of broccoli in a crate, papered over the sides, ends, and bottom, were held in a 24° F. room for 72 hours. On removal from the freezing room the stems were found frozen at the base, but the flower heads were not frozen. After the crate had been held at 55° for 24 hours, no injury could be detected in any of the bunches.

On the market, freezing injury shows first as water soaking of the stem core.

CABBAGE

An unpapered crate containing two layers of heads of new cabbage was held in a 24° F. room for 78 hours. On removal from the freezing room some heads were found frozen solid and others only on the outside to a depth of one-quarter to one-half inch. After 6 days at 60° none of the heads showed any signs of injury.

Several heads of old cabbage, unprotected (not in a container), were placed in a 24° F. room and left for 6 days. On removal and while still frozen, they had a glassy, water-soaked appearance in the heart and some of the larger midribs. After 24 hours at 60° they were completely thawed. When cut lengthwise they looked entirely normal except that the lowermost leaves of the head tended to separate from the stem or heart. Such separation also

occurs in old, unfrozen cabbage, but in the heads discussed here there was no yellowing as in old cabbage.

After 2 days at 18° F. unprotected heads of new cabbage were found frozen solid. On thawing they were found to be worthless—soft, water-soaked, and very leaky.

For a discussion of the rate of cooling of three other lots of cabbage see page 26. (For rate of cooling of one of these see figure 3.)

On the market, cabbage frozen severely enough to show injury usually is worst affected in the stem and the heart leaves. These parts are water-soaked and light brown. Severe or frequent freezing causes the outer leaves to become paper thin. Slight injury is often revealed by brown streaks in the stem (or heart).

CARROTS

EXPERIMENTAL OBSERVATIONS

Carrots were stored at 18° F. for 51 hours and then at 14° for 48 hours more. The container was a standard crate lined with paper and with a pad under the lid. No extra paper was placed over the outside. The carrots had been topped, leaving 2-inch leafstalk stubs. (For data on the rate of cooling of carrots, see also page 25 and figure 1.) On removal of the crate from the freezing room all the easily accessible roots were found frozen and numerous roots at the top were seen to be cracked lengthwise. After 72 hours at 45° all the roots had thawed. Cracking was fairly uniform throughout the crate, 48 percent being cracked and 52 percent not cracked. In many of the cracked roots the outer layer, to a depth of about one-eighth inch, had separated from the central cylinder and could easily be removed. There were no internal cracks extending outward from the center (radial cracking) except in a few specimens that were spongy and leaky. Some of the leafstalk stubs were plainly frozen to death (limp and water-soaked); others appeared to be uninjured. After 72 hours at 45° there was no increase in radial cracking and no softening.

Another standard crate of carrots with the tops attached was held in a 20° F. room for 48 hours. The crate was not lined but was papered over the sides, ends, and bottom. On removal from the freezing room the roots next to the sides, ends, and top of the crate were found frozen. After 12 hours at 60° the only injury that could be detected was in the limp, water-soaked tops that were exposed along the edges of the lid. After 4 more days at 60° the tops and roots at the top of the crate were wilted and the roots had a poor flavor. Roots away from the outside of the crate showed no injury and had a good flavor. No lengthwise cracking was observed in any roots used in this test.

MARKET OBSERVATIONS

Freezing injury of carrots seen on the market consists of flabbiness of roots, radial cracking of the central cylinder, and tangential cracking of the outer cortex. Water soaking is rarely seen.

CAULIFLOWER

Cauliflower was held in a crate containing 1 dozen heads in a 20° F. room for 31 hours. The sides, ends, and bottom of the crate were papered. On removal from the freezing room the leaves and curd were found frozen solid. After 17 hours at 60° there was no evidence of injury to either leaves or curd. After repeated freezing and thawing, the edges of the outside leaves became dry and papery and had a bluish color. The curd was not affected, and when cooked it had a normal flavor.

Cauliflower repeatedly or severely frozen in transit or on the market has a glassy, water-soaked appearance of the pith of the stem and of part or all of the curd. A pronounced odor of spoiled cabbage is given off. At room temperature the water-soaked areas are quickly invaded by soft rot bacteria.

CELERY

EXPERIMENTAL OBSERVATIONS

Blanched celery was held in a standard crate in a 20° F. room for 7 hours. The crate was papered over the sides, ends, and bottom. After 17 hours at 60° all stalks (the entire trimmed plants) showed freezing injury marked by loosening of the epidermis on many of the outer leaf stems. The hearts were unfrozen. Loosening of the epidermis is best demonstrated by twisting the leaf stem, or petiole.

Unblanched Pascal celery was held in a standard crate, which had its ends, sides, and bottom papered, in a 24° F. room for 72 hours. After 3 days at 55° many outside leaf stems of bunches found actually frozen when removed (about one-half of the contents of the crate) were water-soaked and slightly slimy; a few showed pink mold rot (watery soft rot). Many leaf stems that appeared normal on the outside were water-soaked and discolored on the inner surface. Many of the leaf stems, discolored and not discolored, showed wrinkling of the epidermis when twisted.

No flabbiness or drooping of the leaf stems was observed in either the blanched or the unblanched celery.

MARKET OBSERVATIONS

Celery found frozen on the market frequently shows flabby or limp outer leaf stems after it thaws. Furthermore, the epidermis not only becomes loosened but sometimes it peels off. The loosening is often more pronounced in the upper nodes or branches of the leaf stem than in the main leaf stem itself.

GREEN CORN

Green corn was held in a bushel basket in an 18° F. room for 120 hours. The basket was papered around the sides and was covered with a regular basket lid. After about 2 hours the outside husks of the top-layer ears were found frozen but the inside husks were not. After 48 hours only the outside husks of the uppermost ears

were frozen. After 96 hours all ears in the upper part of the basket were frozen hard but those at the center were not. After 120 hours, when the basket was removed from the freezing room, all ears were found frozen. After 24 hours at 45° the corn had a slightly sour smell, the husks and cob were water-soaked, and the grains were watery and much softened.

CUCUMBERS

Cucumbers in a half-bushel basket, papered over the sides and bottom, were held in a 24° F. room for 7 hours. On their removal from the freezing room no injury was observed, and there was none after the cucumbers had been held at 60° for 24 hours.

Other cucumbers were held in a bushel basket in an 18° F. room for 48 hours. The basket was papered around the sides and was covered with a regular basket lid. During the first 5 hours no signs of freezing could be detected, but after 6 hours several cucumbers around the edge of the lid showed numerous circular, water-soaked spots on the surface, mostly about one-sixteenth to one-eighth inch in diameter. A few water-soaked areas one-half inch in diameter were seen. After 24 hours all the top-layer cucumbers were frozen hard. After 26 hours cucumbers halfway down in the basket, both at the sides and in the center, were not frozen. On removal from the freezing room all the cucumbers showed freezing but some at the center were not entirely frozen. After 48 hours at 45° the cucumbers that had frozen were soft, water-soaked throughout, and much wrinkled lengthwise, especially toward the stem end.

Frozen cucumbers seen on the market are completely water-soaked and flabby and are soon invaded by bacteria or fungi.

EGGPLANT

Eggplant was held in an unpapered bushel basket in a 24° F. room for 78 hours. On removal from the freezing room some were frozen solid and others only on the outside to a depth of one-quarter to one-half inch. After 6 days at 60° none showed any sign of injury. After being held 2 more days at 18° they were found frozen solid. On thawing they were slightly browned inside, soft, very leaky, and worthless.

On the market, browning of the flesh and slight shriveling are recognized as signs of moderate freezing.

LEMONS

Lemons were held in a standard crate in an 18° F. room for 75 hours. The crate was not papered, but the lemons in one end were individually wrapped and those in the other were not wrapped. (For rate of cooling of these two lots see figure 2.) After 75 hours at 18° some fruits in both ends of the crate, at or near the center position, were not frozen. After 20 hours at 45° many of the fruits in both ends of the box were found to be soft, watery, and worthless. The percentage of such injured fruits was greatest in

the end where no wrappers were used. Inspection after the box had been held at 36° for 3 weeks showed that the percentage of soft lemons had increased greatly. Percentage figures for the two inspections follow.

Description and treatment:	<i>Percentage soft</i>
Unwrapped, after thawing.....	55
Wrapped, after thawing	25
Unwrapped, after 3 weeks at 36° F.	84
Wrapped, after 3 weeks at 36° F.	57

The fruits not classed as soft were firm and usable.

On the market, frozen lemons have a rind flavor but not the strong, unpleasant, rancid flavor and odor found in watery break-down. Watery break-down is found scattered throughout stacks of boxes and in the center of packs as well as along the edges, whereas freezing injury is likely to be localized. (See also page 18.)

LETTUCE

Lettuce in an eastern crate (2 dozen heads) was held in a 20° F. room for 54 hours. The crate was papered over the sides, ends, and bottom and contained package ice. After 17 hours at 60° the outer leaves of the heads around the outside of the crate had a water-soaked appearance. When these heads were cut, the freezing injury was found to extend through about three layers of leaves. The solid part of the heads was uninjured and not frozen. No freezing injury was found in the heads next to the outside layers. There was still some package ice remaining.

Conditions similar to those just described were found in a crate of lettuce held for 72 hours in a 24° F. room.

On the market, lettuce injured by moderate freezing shows only a few outer leaves glassy. The heads usually remain firm unless there is opportunity for subsequent drying.

ONIONS AND GARLIC

EXPERIMENTAL OBSERVATIONS

Onions in an unprotected net bag of 1-bushel capacity were held at 21° to 24° F. for 54 hours. The bulbs varied greatly in size and many of them had sprouted. Large bulbs of the Yellow Bermuda variety also were held loose in a box in the same room during the same period. On removal from the freezing room all the onions in the box, except a few at the center, were found frozen. Of the 326 onions in the bag 117 (approximately 36 percent) were not frozen. Most of these were at or near the center of the mass of bulbs. The frozen onions in both the bag and the box were hard and had a glassy, water-soaked appearance.

After being held for 3 days at 31° F. both lots showed the symptoms described under Market Observations.

MARKET OBSERVATIONS³

The average freezing point of onion bulbs is about 30° F. Although some onions may freeze at a fraction of a degree higher or lower, this temperature may be taken as the danger point. Under some conditions onions standing on track or in storage may be undercooled to a temperature of 25° or lower for a short time without becoming frozen or otherwise injured. A slight jar will cause undercooled products to freeze immediately; therefore onions rarely undercool during transit.

Individual onions vary considerably in their reaction to low temperature. Some bulbs in a lot may freeze quickly when they reach a temperature of 30° F. and show severe injury when they thaw. Others may not freeze, or if they do freeze they may thaw out without injury.

Onions injured by freezing show water-soaked, grayish-yellow fleshy scales when cut. In slight freezing the outer fleshy scales alone are affected, but when the bulbs are exposed to low temperatures for a prolonged period the inner scales may also become water-soaked and discolored. Usually the entire scale is injured all the way around the bulb, but the neighboring scales inside and outside may or may not show injury. Irregularly shaped opaque areas occur in many of the watery transparent scales.

Garlic bulbs do not freeze until a temperature of approximately 25° F. is reached. The frozen tissues are discolored and water-soaked in the same way as those of onions.

In cases of slight freezing injury of onions and garlic there may be little loss if the bulbs are spread out so that the injured scales can dry thoroughly. Experimental evidence indicates that frozen onions will show less injury and remain in a better general condition if thawed out at 40° F. rather than at a higher temperature.

ORANGES AND GRAPEFRUIT

EXPERIMENTAL OBSERVATIONS

One standard crate of oranges and one of grapefruit were held in an 18° F. room for 25 hours. The crates were not papered, but the fruits in one end of each crate were individually wrapped and those in the other were not wrapped. Immediately after removal from the freezing room all top-layer fruits were found frozen but those halfway down and away from the sides and ends in both the wrapped and the unwrapped lots felt normally soft. Evidently they were not frozen. The crates were held at 45° for 24 hours after removal from the freezing room; the only marked symptoms in any of the fruits were a definite softening and slight off-flavor of a few from the top layers, both wrapped and unwrapped.

After 13 days at 36° F. all fruits cut were slightly off in flavor, but otherwise there was no change from the condition noted at the time of the first inspection. No pitting of the peel and no drying or separation of segments was noted.

³ Adapted from RAMSEY, G. B., and WIAIT, J. S. MARKET DISEASES OF FRUITS AND VEGETABLES: ASPARAGUS, ONIONS, BEANS, PEAS, CARROTS, CELERY, AND RELATED VEGETABLES. U. S. Dept. Agr. Misc. Pub. 440, 70 pp., illus. 1941. (See p. 10.)

MARKET OBSERVATIONS ⁴

Freezing injury in transit is likely to occur in the fruit next to the side walls and along the floor of the car rather than in that in the body of the load. It seldom shows in the form of drying out so characteristic of fruit frozen on the tree. Oranges and grapefruit are often bitter in flavor for a time after thawing, but this is not a consistent condition. If the freezing has been severe, the rind may show effects ranging in severity from almost typical brown stain to leaden-gray discolored areas of varying size, which greatly resemble watery break-down. The affected rind tissues may or may not be sunken, but when severely frozen they usually become soft and mushy and are underlain by mushy pulp tissue.

Freezing damage is best seen by cutting off both ends of a fruit, then cutting lengthwise through the rind of the central portion remaining, and pulling the segments apart. If the fruit has been frozen the membrane between the segments will show a soaked condition and usually a number of white specks, which are hesperidin crystals (naringin in grapefruit) resulting from the freezing. However, the presence of crystals is not necessarily an indication that the fruit has been frozen. They may also result from the application of heat to the fruit or from rapid drying out of the tissues. In tangerines the hesperidin crystals occur in the pulp as well as on the segment walls and are seen even more readily than in oranges when a cross-section cut is made. Freezing damage may be confined to a part of the fruit, in which case the signs suggested will be found in the affected part. The method of examination just described is particularly useful for California oranges. Florida oranges are not so easily examined in this way but are more likely to show the mushy condition in cross section.

Lemons and grapefruit show the damage in cross section much more plainly than oranges do, although it is desirable at times to pull grapefruit sections apart as recommended for oranges. If lemons have been seriously damaged the pulp becomes mushy at once after thawing.

In addition to the symptoms just described grapefruit shows a milky appearance of the pulp, which is in marked contrast to the very light amber color and the almost transparent condition of unfrozen pulp. The contrast is especially noticeable in fruits that have been frozen in small spots or on one side only. The milky appearance of the pulp is also found in grapefruit that has been in storage for 8 to 10 weeks, and it may be accompanied by a bitter taste. However, such fruit is not mushy and watery unless affected by watery break-down; in such a case a positive diagnosis must depend on a consideration of the history of the fruit and the conditions under which the injury is found.

Citrus fruits frozen on the tree show a number of symptoms similar to those described under transit freezing if examined soon after the freezing occurs. After a few days, however, additional symptoms appear. First and most characteristic among these is a buckling of the partition walls at the stem end of the

⁴ Adapted from ROSE, D. H., BROOKS, C., BRATLEY, C. O., and WINSTON, J. R. MARKET DISEASES OF FRUITS AND VEGETABLES: CITRUS AND OTHER SUBTROPICAL FRUITS. U. S. Dept. Agr. Misc. Pub. 498, 57 pp., illus. 1943. (See pp. 27 and 28.)

fruit, with or without drying of the pulp. Small pits or pitted areas may also develop in the rind on any part of the fruit. In fruit on the market, picked several days after it had been frozen on the tree, the injury is manifest by woodiness of the pulp or by open spaces between the segments due to the collapse and drying out of some of the juice sacs. Cavities usually appear in the orange pulp before open spaces develop between the segment walls. Later, when considerable drying out of the pulp has occurred, small open spaces between the segment walls may be found. Sometimes only one or two segments will show drying-out effects and all or only a part of the segment may be affected.

There are, of course, all degrees of dryness, from very slight to total. In the practical handling of citrus fruit three degrees of dryness are recognized: (1) Slightly open, when the cut surface shows a slight open space between the segment walls and the juice sacs but the surface of the pulp appears juicy. (2) Distinctly open, when the cut surface shows large open spaces but the pulp still appears juicy. (3) Dry, when the cut surface shows no large open spaces but the fruit seems to have dried out evenly all through and the color of the pulp shows it to be almost devoid of juice, or when the fruit has dried out with some of the segments more or less collapsed.

Drying in oranges usually progresses from the stem end, whereas in grapefruit it may proceed from either or both ends or it may begin around the outside of the pulp. Drying is not found at the center of the fruit except in extreme cases. If an orange that has been frozen is examined a few days after it thaws, it will usually show the hesperidin crystals already mentioned on the membrane or rag that separates the segments of the pulp. On the other hand, the crystals are sometimes visible when examination is made within a few hours after the freezing, whereas if it is not made until several weeks afterward they may not be so numerous or conspicuous, probably because the more severely frozen fruit falls soon after the freeze. When examined on the market tree-frozen fruit that has remained on the tree for several weeks after freezing has a rind that is thicker than normal, especially over the damaged part of the fruit.

As differentiated from granulation, which sometimes occurs in fruit on the tree, dryness from freezing results through the emptying and subsequent collapse of juice sacs due to disappearance of the juice. In granulation the juice sacs do not collapse but become filled with gelatinous or solid matter.

PARSNIPS

Parsnips were kept in a $\frac{5}{8}$ -bushel hamper in a 24° F. room for 28 hours. The hamper was papered over the sides and bottom. On removal from the freezing room the roots around the sides and on top were found to be frozen hard. Freezing was less severe at the center. After 17 hours at 60° there was no sign of injury in any of the roots in the hamper. After 10 days more at 60° the roots were in good condition except for one small root affected with rhizopus rot.

PEAS

Peas were kept in a bushel hamper in a 24° F. room for 50 hours. The hamper was papered over the sides and bottom. On removal from the freezing room many pods over the top and next to the sides of the hamper were found frozen. After 24 hours at 60° no evidence of freezing injury was found.

A few pods not in a container were placed at 24° F. and left for 24 hours. When thawed out at 40° the pods were found to be soft and water-soaked; the shelled-out peas were generally water-soaked and darker green than unfrozen ones. Numerous whitish spots were noted, but these were on the pods and evidently were due to the drying out of bruised or rubbed areas and not to freezing.

PEPPERS

Peppers were held in a bushel basket in a 24° F. room for 24 hours; the basket was papered over the sides and bottom. After 6 hours at 60° freezing injury was spotty. Some specimens showed no injury; in others the entire outer wall was soft, water-soaked, and darker colored than that of unfrozen ones. There was no browning of any part of the peppers. This same lot was returned to a temperature of 24° for 48 hours more. At the end of that time all the peppers were found frozen and, after they had thawed out, a few around the outside of the basket showed browning of cores and seeds, as well as water soaking. Such peppers were soft and worthless.

POTATOES

MARKET OBSERVATIONS ⁵

The symptoms of freezing injury in potatoes vary, depending upon the kind of tissues killed, the amount of tissue involved, and the consistency and color of the affected regions. Which of the symptom complexes will develop depends upon whether the injury is due to (1) long exposure to temperatures just below the freezing point, (2) moderately long exposure to very low temperatures, (3) moderately short exposure to temperatures just at the freezing point, or (4) short exposure to temperatures far below the freezing point. In the first two cases, almost all the tissues may be killed and both external and internal symptoms may appear shortly after thawing. In the last two cases only the most susceptible tissues are killed and no external symptoms are apparent for weeks or months. Short exposures generally produce slight injury of the net or ring type or a combination of these; longer exposures the blotch type, often in combination with the net and ring types. The restricted or limited type of injury is known as freezing or frost necrosis.

Before thawing, frozen potato tissue no longer possesses the crispness of the normal tissue. It is abnormally firm, looks dull, and does not cut readily or with snap. This is due to the presence

⁵ Adapted from LINK, G. K. K., and RAMSEY, G. B. MARKET DISEASES OF FRUITS AND VEGETABLES: POTATOES. U. S. Dept. Agr. Misc. Pub. 98, 63 pp., illus. 1932. (See pp. 18 and 19.)

of ice. When ice occurs in only part of the tuber, its presence can be detected at times by a crunching sound if, while held to the ear, the tuber is pressed between the fingers.

Tubers that are frozen solid collapse promptly upon thawing, becoming soft and watery. Their wet surfaces make detection and sorting out easy. The presence of moisture on a tuber is not necessarily a sign of freezing injury, however, since cold tubers when brought into moist air with a temperature higher than their own very readily condense water from the air on their surfaces. Sometimes if only a part of a tuber is exposed to freezing temperature that portion is frozen to death and upon thawing becomes turgid and blisterlike and the skin frequently discolours. If tissues that have been frozen to death are cut shortly after thawing, they may appear dull and colorless at first. Upon exposure to the air they frequently pass promptly through pink and red stages and ultimately become brown, gray, or inky black. The rate of development of these colors depends upon the temperature of the air. At temperatures below 75° F. several hours may be required, while only ½ to 1 hour may suffice at higher temperatures. The occurrence of these color changes is also determined by the extent to which air reaches the affected tissues.

When extensive areas of tissues are killed by freezing they usually become infected with bacteria, which cause foul-smelling, slimy, or sticky rots if thawing takes place in a warm, humid atmosphere. They dry down to a mealy or tough, leathery, granular, chalky mass of starch and tissue remnants if they thaw in cold or dry air. Tubers that have only one side frozen frequently have the killed portion sharply set off from the unaffected area by a purplish or ultimately brown line of corky tissues. Often infection by species of *Fusarium* sets in before the unaffected cells are sealed off by the corky layer.

From experience with potatoes in the field, in storage, and in transit and from experiments it is generally known that when a lot of tubers has been exposed to low temperatures for a long enough time for some to freeze solid, there frequently are others which do not freeze at all and still others which seem to be unaffected so far as external appearances indicate, but when cut they may show the various types of symptoms known as freezing or frost necrosis.

The mildest type of freezing necrosis is one marked by tissues that are drier than the surrounding ones and that have a grayish-white tint. When the injured tissues are cut soon after thawing, they may turn red in a short time and finally become brown. In uncut tubers, even after a long time, the only sign of injury is a grayish, dull, dry, collapsed appearance of some of the tissues.

Generally, however, freezing necrosis is marked by decided discolorations. These may not be apparent immediately after thawing, but they usually set in after 5 or 6 hours. Usually the color changes from dull white to pink or brick red and finally to gray, brown, or black.

There are several types of discoloration. One, the ring type, is limited to the vascular (water-conducting) ring and immediately adjoining tissues and is characterized by pronounced blackening.

Another, the net type, is marked by more or less blackening of the vascular ring and the finer strands which extend from it into adjacent tissue. Both types are frequently restricted to the stem end. Finally, there is a blotch type, marked by irregular patches ranging in color from an opaque gray or blue to sooty black. These patches occur everywhere in the tuber, though most generally in the vascular ring and the cortex. When these blotches are in the cortex they may be apparent externally in clean tubers with white skins. This is the only type of freezing necrosis that may be visible externally. If tubers affected with any or all of these types of freezing necrosis are held in storage, they generally shrivel or wilt more than unaffected tubers. Excessive shriveling alone, however, cannot be relied upon as a sign of freezing necrosis.

It is popularly believed that the symptoms here described as freezing necrosis are not due to freezing but to chilling, since freezing, it is contended, is always followed by a complete breakdown after thawing. This is not the case. Freezing necrosis is as truly a freezing injury as the complete type, and it does not occur unless ice is formed in the tissues. The difference lies in the fact that not all cells of the tuber, but only those that become discolored, have been killed.

RUTABAGAS

EXPERIMENTAL OBSERVATIONS

Rutabagas, with starting temperatures of about 36° F. and 64°, in bushel bags were kept in a 25° room for 29 and 31 hours, respectively. A third bag with a starting temperature of about 57° was held for 24 hours in an 18° room. After thawing at 45° for 5 days neither the lightly frozen nor the severely frozen lots showed injury of any kind. When the roots were cut while still frozen there was a water-soaked ring about one-quarter to one-half inch deep around the outside, but this disappeared after the roots had thawed. A second freezing at 18° for about 24 hours caused no detectable injury.

For a discussion of the rate of cooling of two other lots of rutabagas see pages 26 and 27. The rate of cooling of one of these is shown in figure 3.

MARKET OBSERVATIONS

Severely frozen roots remain fairly firm but are water-soaked and light brown. Free water runs from cut surfaces. A pronounced mustard odor is given off.

There are considerable variation among different lots of rutabagas and considerable difference of opinion among market handlers as to the importance of freezing injury in this crop. The situation can be summed up as follows: Most lots show no damage after thawing, but some become flabby and are predisposed to decay. Some dealers believe that one or two freezes do not cause injury but that more do; others believe that the extent of the injury depends on the temperature and on whether the roots are handled while frozen and soon after thawing.

SPINACH

EXPERIMENTAL OBSERVATIONS

Spinach in a bushel basket was held in a 24° F. room for 96 hours. The basket was papered over the sides and bottom. On removal from the freezing room the mass of spinach was cut through vertically from side to side of the basket. Freezing was found to extend inward about 1½ inches from the top and 3½ inches from the sides. One-half of the lot was left in the basket and this and the portion that had been removed were held in a 40° room for 4 days. At that time the only injury found was in the topmost leaves, which were bruised and water-soaked where they had been in contact with the lid. The basket was then repacked and returned to 24° for a second freezing. It was removed after 2 days and thawed at 60°. No injury was found except in the uppermost leaves that were against the lid and had been bruised in handling. After 5 days at 60° spinach that had frozen at 24° developed slimy soft rot in the uppermost injured leaves.

MARKET OBSERVATIONS

The frozen leaves of spinach are easily bruised during unloading and handling. This bruising gives a water-soaked, collapsed appearance to plants in the tops of baskets. Plants that protrude under the lid are particularly likely to be injured.

SQUASHES

Acorn squashes in a ⅝-bushel hamper were kept in a 24° F. room for 6 days. The sides and bottom of the hamper were papered, and paper was also laid loosely over the top. Thirty-six hours after removal from the freezing room (12 hours in 32° after standing in a handling room for 24 hours at about 60°), the squashes from the top of the hamper were soft and water-soaked and had a granular appearance in the flesh and a fermented smell. Soft ones were found all the way down to the bottom of the hamper, but two that apparently had not frozen were noted. Many of the injured squashes showed small white spots on the outside, produced by localized blistering of the skin. After thawing, all squashes from this hamper were darker externally than unfrozen ones saved for comparison.

Two unprotected Blue Hubbard squashes were held in a 24° F. room for 6 days. On removal from the freezing room these squashes showed small lens- or disc-shaped masses of ice throughout the flesh but the flesh was not discolored. On thawing at 60° for 24 hours the flesh contained many small crescent-shaped cracks. There was no discoloration, no water-soaked condition, and no off-odor.

The most common indications of freezing injury of Hubbard squashes seen on the market are drying of the flesh after thawing and a tendency to develop decay spots in the shell.

Summer squashes (Yellow Crookneck) were kept in a bushel basket in a 24° F. room for 24 hours. It was papered over the

sides and bottom. After 6 hours at 60° all specimens showed some injury but only in limited areas over the surface. No injury was noted in the inner flesh. The outer wall, where affected, showed a dark, water-soaked appearance on the surface and a similar condition extending inward about an eighth of an inch. Under light pressure the injured tissues readily exuded a watery juice. When the squashes were left for 24 hours at 60° the injured areas on the surface began to show mold growth.

SWEETPOTATOES

Sweetpotatoes in an unpapered $\frac{5}{8}$ -bushel hamper were held in an 18° F. room for 51 hours. After 5 days at 45° many of the roots were soft and when cut were very leaky. The cut surface did not exude a milky juice as normal unfrozen roots do. All roots that were cut had a darkened band around the outside of the cross section, extending inward one-eighth to three-sixteenths inch. The flesh was mottled light gray to brown or reddish and had a sour, off-smell. All roots in the hamper showed injury.

Other tests showed that an exposure of only 3 or 4 hours to 22° F. caused unprotected sweetpotatoes to turn brown inside. The first region of the root to be injured is the ring of water-conducting tissue about one-sixteenth to one-eighth inch under the skin.

TOMATOES

Tomatoes in an unpapered, lidded 30-pound lug were held in an 18° F. room for 48 hours. After 6 hours no freezing could be detected, but after 7 hours a few fruits next to the lid were beginning to freeze. On removal from the freezing room all tomatoes around the outside of the mass of fruits were found frozen hard, but those in the center layer, away from the sides, ends, bottom, and lid, were still unfrozen. These comprised about one-quarter of the total number of tomatoes in the lug. When the frozen tomatoes thawed at 45°, they become soft, watery, and worthless.

Unprotected tomatoes laid out singly in the same freezing room began to freeze on the outside in about 3 hours. After 6 hours the freezing extended inward about one-half inch from the surface of each fruit.

TURNIPS

Turnips were held in a bushel basket in a 24° F. room for 144 hours. The basket was papered over the sides and bottom, and paper was also laid loosely over the top. Freezing temperatures in the turnips were recorded after 19 to 21 hours, but no injury was found when frozen roots were removed and thawed. The basket was, therefore, left in the freezing room for 6 days in order to obtain injury.

Thirty-six hours after removal from the freezing room (12 hours at 32° F. after being held for 24 hours at about 60°) those from the top of the basket were dirty gray on the outside, soft, and water-soaked and had a fermented smell. The skin had a blistered appearance produced by the formation of small lens-shaped masses

of ice between the skin and flesh. Softened, watery turnips were found all the way to the bottom of the basket, but there were a few that showed no signs of injury. In some of the injured specimens the flesh had turned from white to light brown.

RATES OF COOLING OF FRUITS AND VEGETABLES

The rates of cooling of wrapped and unwrapped apples and of topped carrots are given in figure 1, of wrapped and unwrapped lemons in figure 2, and of rutabagas and cabbage in figure 3.

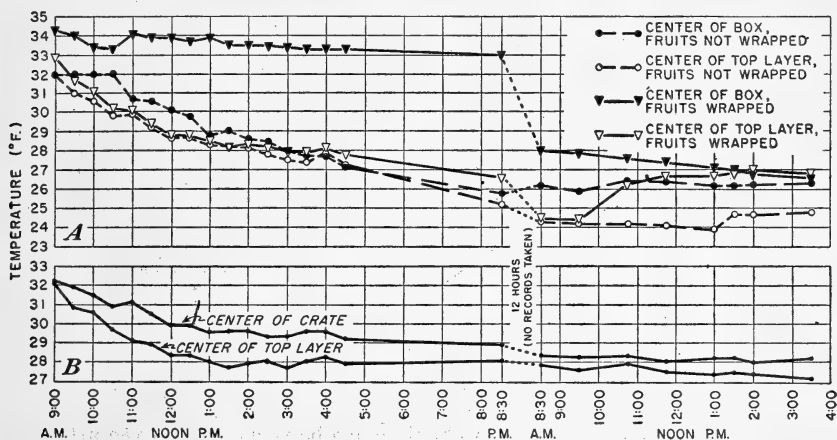


FIGURE 1.—Rate of cooling of topped carrots and of wrapped and unwrapped apples in packages not papered over the outside in an 18° F. room: A, Apples; B, carrots.

The following comments on the rate-of-cooling experiments and the results will help to bring out facts shown by figures 1 to 3; they also supplement the statements on apples (p. 5), cabbage (p. 12), carrots (p. 13), lemons (p. 15), and rutabagas (p. 22).

(1) Wrapped and unwrapped apples in eastern boxes at a starting temperature of approximately 32° F. were placed in an 18° room (fig. 1). The most exposed apples in both boxes (along the edges, on top) began to freeze in about 3 hours after the test was started. Freezing began after about 7 hours at the center of the box of unwrapped fruit but not until after about 24 hours at the same position in the box of wrapped fruit.

(2) Topped carrots with a starting temperature of about 32° F. in a lined standard crate with a pad under the lid were placed in an 18° room (fig. 1). Freezing began in exposed roots at the top in about 3 hours but not until after about 6 hours at the center of the crate.

(3) Lemons in a standard California lemon crate were placed in an 18° F. room (fig. 2). The lemons in one-half of the box were wrapped, whereas those in the other half were without wraps. Their average starting temperature was approximately 32°. After 3 hours exposed lemons in the top layer, both wrapped and unwrapped, began to freeze on the outside. After 7 hours a few

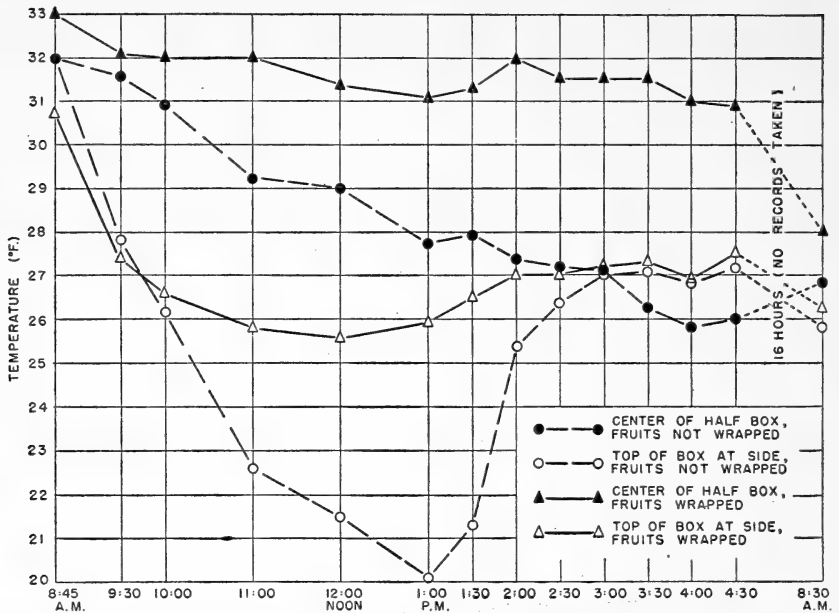


FIGURE 2.—Rate of cooling of wrapped and unwrapped lemons in a crate not papered over the outside in an 18° F. room. Undercooling occurred in the top layer at the side in both wrapped and unwrapped fruits, but the rise to the true freezing point probably came between 4:30 in the afternoon and 8:30 the next morning, during which time no temperature readings were made.

wrapped and unwrapped fruits in the middle layer at the end of the box were frozen, while others were not. At the center of the half box, unwrapped fruit began to freeze after 7 to 8 hours but wrapped fruit did not begin to freeze until after about 24 hours. After 75 hours at 18°, some wrapped and unwrapped fruits in both ends of the box at or near the center position in each half were still not frozen.

(4) Two bags of rutabagas (1 bushel each) having starting temperatures ranging from 54.9° to 59.3° F. were placed in an 18° room. One of the bags remained motionless during the test; the other bag was shaken continuously on a jolting machine, to simulate conditions in a moving railroad car. The roots at the top and sides of both bags began to freeze in about 7 hours. There was no evidence that the jolting made any difference in the length of time required for the roots to freeze.

(5) New cabbage in bushel crates, having starting temperatures ranging from 50.6° to 54.7° F., was held in an 18° room under the conditions just described for rutabagas. Freezing occurred at the top and around the sides of both crates in about 9 hours. There was no noticeable effect of the jolting.

(6) New cabbage in a bushel basket and rutabagas in a bushel bag were placed in a 25° F. room. Their starting temperature was approximately 64°. The rutabagas began to freeze in 18 to

20 hours. Outside leaves on the uppermost heads of cabbage showed freezing in about 7 hours, but even in these heads freezing was only about one-half inch deep after 48 hours. None of the heads that lay deep in the basket showed any freezing during the 48-hour period.

(7) New cabbage in a bushel basket, having a starting temperature of about 36° F., was placed in a 25° room. Freezing of the outside of the uppermost heads began in 1 hour but did not occur to the extent of one-quarter inch inward from the surface until after 7 hours.

(8) Rutabagas in a bushel bag, having a starting temperature of about 36° F., were placed in a 25° room. Freezing of the out-

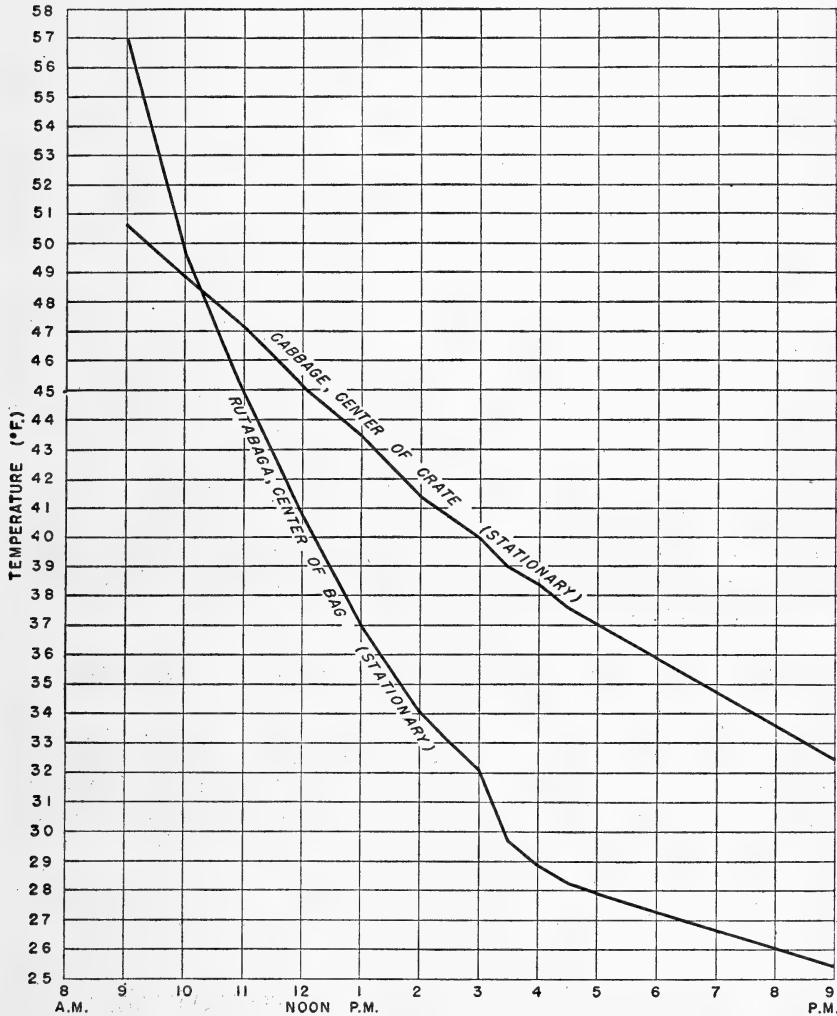


FIGURE 3.—Rate of cooling of rutabagas in a burlap bag and of new cabbage in a crate at different starting temperatures in an 18° F. room. Packages were not protected by paper.

side of the most exposed roots began in about 2 hours. At a depth of three-quarters inch it did not begin until after 7 hours. After 24 hours at 25° the most exposed heads of cabbage (example 7, p. 27) were frozen to a depth of one-half to three-quarters inch but the heads at the center of the basket were still unfrozen. After 24 hours all the rutabagas were frozen solid.

It should be remembered that in all the examples given, the test lot consisted of only one or two commercial packages. Under such circumstances the rate of cooling would be more rapid than in the interior of a stack of packages equivalent to a truckload or a half or a whole carload. The rates of cooling shown are about what could be expected in the outside packages of large stacks or blocks.

The difference shown in figure 3, namely that cabbage, except for the outermost leaves of exposed heads, froze much more slowly than rutabagas, probably depended directly on a difference in the physical characteristics of the two vegetables. The cabbage heads were loose and were therefore protected internally by the insulating effect of numerous air spaces between the leaves. Rutabagas are solid and therefore without protective internal air spaces. Another important difference between the two vegetables is that cabbage produces heat more rapidly (respires more rapidly) than rutabagas. This extra heat in containers packed with cabbage would give added protection against freezing.

A slow rate of freezing similar to that observed in cabbage has been noted in masses of lettuce and spinach in crates or baskets and to some extent in other leafy vegetables and in peas and snap beans in hampers or baskets. The reasons for the retardation of freezing in all these instances are undoubtedly those mentioned for cabbage—air spaces within the mass of packed produce and a rather high rate of production of heat by the produce.

In the consideration of examples 6, 7, and 8 an important fact to be noted is that the cooler the vegetables when placed in the freezing room the sooner they froze. This important fact must always be kept in mind by those concerned with the handling and protection of fruits and vegetables that are likely to be subjected to freezing temperatures.

FREEZING NOT ALWAYS INJURIOUS TO PRODUCE

At this point a word of caution is necessary. It should not be assumed that produce is ruined and must be counted a total loss merely because it is found frozen. Much depends on (1) what the produce is, (2) how low its temperature goes during the freezing period, (3) how long it remains frozen, and (4) how it is handled after freezing occurs. Suggestions concerning this last point will be found on page 3. (See also pages 2 and 4.) Careful attention to them should result in saving produce that otherwise might be thrown away or unjustifiably sacrificed on the market. Information on items 2 and 3 may not always be available, but if it is it should be taken into consideration. As stated previously (p. 2), hard freezing, say at a temperature of 15° to 18° F., is more injurious than freezing at a temperature only slightly below the freezing point of the produce, especially if the low temperature is

maintained for several days. Under such extreme treatment, fruits and vegetables may become frozen to death and do not return to normal appearance or condition when they thaw. *Repeated* freezing and thawing are injurious to products, such as apples, sprouting broccoli, brussels sprouts, cabbage, cauliflower, and onions, that are injured very little if at all by only one light freezing unless they are handled while frozen.

Certain fruits and vegetables are susceptible to chilling injury by temperatures that are not low enough to cause them to freeze. The relative susceptibility of these products to such injury is shown in tables 2 and 3.

TABLE 2.—*Commodities susceptible to chilling injury at only moderately low temperatures (45° to 55° F.)*¹

Commodity	Freezing point	Dangerous temperature	Limit of safe exposure	Character of injury
Avocados.....	°F. 27	Below 42 2..	4 weeks to 2 months, depending on variety...	Internal browning.
Bananas.....	30	Below 55 or 56.....	Only a few hours.....	Dull color when ripened.
Lemons.....	28	Below 50.....	About 4 weeks.....	Pitting, membranous stain, and red blotch.
Limes.....	29	Below 45.....	6 to 8 weeks.....	Rind spotting.
Pineapples....	(3)do.....	1 to 3 weeks.....	Dull green color when ripened.

¹ Temperatures lower than these cause more serious injury.

² For commercially important varieties.

³ Mature green, 29.1°; ripe, 29.9°.

TABLE 3.—*Commodities susceptible to chilling injury at temperatures close to 32° F.*

Commodity	Freezing point	Dangerous temperature	Limit of safe exposure	Character of injury
Cranberries.....	°F. 27	Below 34....	About a month..	Rubbery consistency and diffusion of red color through the flesh.
Cucumbers.....	30	Below 40....	About 2 weeks..	Water-soaked spots on surface.
Eggplant.....	30do.....	About 10 days..	Internal browning and dried-out surface spots.
Potatoes, white..	29do.....	About 1 week..	Sweetening.
Sweetpotatoes....	29	{ 40 50 to 55... }	{ About 2 to 3 weeks. 6 weeks to 2 months. }	Decay.
Tomatoes	30	{ 32..... 40..... }	{ About 8 days 2 to 3 weeks }	Susceptibility to decay; fruit of poor quality and color when ripened.

From the results of experiments, the observation of produce under commercial conditions, and the experience of commercial operators various fruits and vegetables can be grouped as follows on the basis of their susceptibility to freezing injury.

	Freezing point (°F.) ¹		Freezing point (°F.) ¹
Most susceptible:		Moderately susceptible—Continued.	
Asparagus	30	Grapes	25-28
Avocados	27	Lettuce	31
Bananas	30	Onions	30
Beans, lima	30	Oranges and grapefruit.....	28
Beans, snap	30	Parsley	(²)
Berries	30	Peaches and plums	29
Cucumbers	30	Pears	28
Eggplant	30	Peas	30
Lemons	28	Squash, winter	29
Limes	29	Least susceptible:	
Peppers	30	Beets	27
Potatoes, white	29	Brussels sprouts	(²)
Squash, summer	29	Cabbage (old and Savoy) ..	31
Sweetpotatoes	29	Carrots	29
Tomatoes	30	Cauliflower	30
Moderately susceptible:		Kale	(²)
Apples	28	Parsnips	30
Broccoli, sprouting	29	Rutabagas	30
Cabbage (new)	31	Salsify	29
Celery	30	Spinach	30
Cranberries	27	Turnips	30

¹ In most cases these are the approximate average freezing points; it should be remembered that individual specimens may freeze at slightly higher or slightly lower temperatures.

² Exact freezing point not known.

In this tabulation no attempt is made to arrange the commodities in order of susceptibility to freezing injury within each of the three groups. It is felt that probably no two persons, no matter how experienced, would agree on what the order should be. Furthermore, the susceptibility of various fruits and vegetables to freezing and to some extent to freezing injury will depend on whether they are packed tightly or loosely in the containers, whether they are wrapped or not, and whether they are in tight boxes, baskets, or barrels or in slatted crates or hampers. Variations in any of these factors might make a difference in determining in which group a given commodity should be placed. This fact would be of most importance if the classified list were used by commercial operators as a guide in handling the various commodities in severely cold weather.

It is evident from the tabulation that the freezing point of a commodity gives little indication of the damage to be expected from freezing. For example, tomatoes and parsnips have the same average freezing point (30° F.), yet parsnips can be frozen and thawed several times without serious injury whereas tomatoes are severely damaged or utterly ruined by one freezing. Bananas freeze at 30°, avocados at 27°, and spinach at 30°. Bananas, however, are chilled by exposure to temperatures below 55° to 56° for more than a few hours and do not color normally afterward when ripened at 65° to 70°. Avocados are very sensitive to low temperatures; some varieties are injured by exposure to temperatures of 50° to 53° for 15 days, and even the most resistant cannot safely be stored at a temperature as low as 37° for more than about 4 weeks. Spinach will withstand repeated freezing

and thawing without sustaining serious injury if it is not handled while in a frozen condition.

The freezing point of cabbage is 31° F. and of white potatoes 29°. Cabbage, however, can be frozen and thawed two or three times without being permanently damaged, provided the temperature does not go so low that the cabbage is frozen to death and it is not handled while frozen; potatoes, on the other hand, are permanently, although only slightly, injured if some parts of the tubers are in a frozen condition for only 15 minutes.

If the root crops listed in the third section of the tabulation have tops, the bacterial soft rot organism is likely to attack the tops if they become frozen and then thaw. The roots of beets, carrots, salsify, and parsnips are not visibly damaged by moderate freezing if not handled while frozen; after thawing they are usable for food and should be salable if the tops are removed.

