

CHAPTER 23

VEGETABLES

<i>Product Selection and Quality Maintenance</i>	23.1
<i>In-Transit Preservation</i>	23.2
<i>Preservation in Destination Facilities</i>	23.5
<i>Refrigerated Storage Considerations</i>	23.5
<i>Storage of Various Vegetables</i>	23.7

LOSSES (shrinkage) in marketing fresh vegetables (harvesting, handling, packing, storing, and retailing) are caused, in part, by overly high temperatures during handling, storage, and transport, which increase ripening, decay, and the loss of edible quality and nutrient values. In some cases, freezing or chilling injury from overly low temperatures may be involved. Other serious losses are caused by mechanical injury from careless or rough handling and by shrinkage or wilting because of moisture loss. Shrinkage can be reduced substantially by following recommended handling, cooling, transport, and storage practices. Improved packaging, refrigerated transport, and awareness of the role of refrigeration in maintaining quality throughout marketing have made it possible to transport vegetables in field-fresh condition to distant markets.

This chapter covers postharvest handling, cooling, packaging, in-transit preservation, and storage at destination locations for fresh vegetables. It also gives storage requirements for specific vegetables, including potential product deterioration due to improper handling and storage conditions. Vegetable precooling is covered in [Chapter 14](#), and vegetable processing and freezing is covered in [Chapter 26](#).

PRODUCT SELECTION AND QUALITY MAINTENANCE

The principal hazards to quality retention during marketing include

- Metabolic changes (composition, texture, color) associated with respiration, ripening, and senescence (aging)
- Moisture loss with resultant wilting and shriveling
- Bruising and other mechanical injuries
- Parasitic diseases
- Physiological disorders
- Freezing and chilling injury
- Flavor and nutritional changes
- Growth (sprouting, rooting)
- Ethylene-caused injury

Fresh vegetables are living tissues and have a continuing need for O₂ for respiration. During respiration, stored food such as sugar is converted to heat energy, and the product loses quality and food value. In maintaining commodity temperatures during storage or transportation, some of the refrigeration load can be attributed to respiration. For example, a 10 Mg load of asparagus cooled to 4°C can produce enough heat of respiration during a cross-country trip to melt 4 Mg of ice.

Vegetables that respire the fastest often have greater handling problems because they are the most perishable. Variations are due to the type of plant part involved. For example, root crops such as carrots and radish have lower respiration rates than fruit vegetables (cucumber, pepper) and sprouts (asparagus). Refrigeration is the best method of slowing respiration and other life processes.

The preparation of this chapter is assigned to TC 10.9, Refrigeration Application for Foods and Beverages.

[Chapters 8 and 10](#) give more information on the respiration rates of many vegetables.

Vegetables are usually covered with natural populations of microorganisms, which will cause decay given the right conditions. Deterioration because of decay is probably the greatest source of spoilage during marketing. When mechanical injuries break the skin of the produce, decay organisms will enter. If it is then exposed to warm temperatures, especially under humid conditions, infection usually increases. Adequate refrigeration is the best method of controlling decay because low temperatures control the growth of most microorganisms.

Many color changes associated with ripening and aging can be delayed by refrigeration. For example, broccoli may show some yellowing in 1 day on a nonrefrigerated counter, while it remains green at least 3 to 4 days in a refrigerated display.

Refrigeration can retard deterioration caused by chemical and biological reactions. Freshly harvested asparagus will lose 50% of its vitamin C content in 1 day at 20°C, whereas it takes 4 days at 10°C or 12 days at 0°C to lose this amount (Lipton 1968). Recommended conditions for long-term storage are listed in [Table 1, Chapter 10](#).

Loss of moisture with consequent wilting and shriveling is one of the obvious ways to lose freshness. **Transpiration** is the loss of water vapor from living tissues. Moisture losses of 3 to 6% are enough to cause a marked loss of quality for many kinds of vegetables. A few commodities may lose 10% or more in moisture and still be marketable, although some trimming may be necessary, such as for stored cabbage. For more on transpiration, see [Chapter 8](#).

Postharvest Handling

After harvest, most highly perishable vegetables should be removed from the field as rapidly as possible and placed under refrigeration, or they should be graded and packaged for marketing. Since aging and deterioration of vegetables continues after harvest, the marketable life depends greatly on the temperature and care in physical handling.

The effects of rough handling of vegetables are cumulative. Several small bruises on a tomato can produce an off-flavor. Bruising also stimulates the ripening rate of products such as tomatoes and thereby shortens potential storage and shelf life. Mechanical damage increases moisture loss; skinned potatoes may lose 3 to 4 times as much mass as nonskinned ones.

Care should be exercised in stacking bulk bins in storage so that proper ventilation and refrigeration of the product is maintained. Bins should not be of such depth that excessive mass damages the product near the bottom.

Quality maintenance is further aided by

- Harvesting at optimum maturity or quality
- Handling carefully to avoid mechanical injury
- Handling rapidly to minimize deterioration
- Providing protective containers and packaging
- Using preservative chemical, heat, or modified-atmosphere treatments

- Enforcing good plant sanitation procedures while handling
- Precooling to remove field heat
- Providing high relative humidity to minimize moisture loss
- Providing proper refrigeration throughout marketing

Cooling

Rapid cooling of a commodity after harvest, before or after packing or before it is stored or moved in transit, reduces deterioration of the more perishable vegetables. The faster field heat is removed after harvest, the longer produce can be maintained in good marketable condition. Cooling slows natural deterioration, including aging and ripening; slows growth of decay organisms (and thereby the development of rot); and reduces wilting, since water losses occur much more slowly at low temperatures than at high temperatures. After cooling, produce should be refrigerated continuously at recommended temperatures. If warming is allowed, much of the benefit of prompt precooling may be lost.

Types of cooling include hydrocooling, vacuum cooling, air cooling, and cooling with contact ice and top ice. These methods are discussed in detail in [Chapter 14](#). The choice of cooling method depends on factors such as refrigeration sources and costs, volume of product shipped, and compatibility with the product.

Protective Packaging and Waxing

Vegetables for transit and destination storage should be packed in containers with adequate stacking strength and durability to protect against crushing under high humidity. Bulging crates should be stacked on their sides or stripped between layers to keep mass off the commodity. Many vegetables are now stored or shipped in corrugated fiberboard containers, but the weakening of fiberboard materials by moisture absorption at high storage humidities is frequently a serious problem.

Manufacturers have improved the strength and slowed the rate of moisture absorption by fiberboard materials. Special treatment of fiberboard permits the use of certain cartons during hydrocooling and with package and top ice. Cartons may be strengthened for stacking by using dividers, wooden corner posts, and full telescoping covers.

Produce is often consumer-packaged at production locations using many types of trays, wraps, and film bags, which may present special transit and handling problems when master containers for these packages lack stacking strength.

Desiccation often can be minimized by using moisture-retentive plastic packaging materials. Polyethylene film box liners, pallet covers, and tarpaulins may be helpful in reducing moisture loss from vegetables. Plastic films, if sealed or tightly tied, may restrict the transfer of CO₂, O₂, and water vapor, leading to harmful concentrations of these respiratory gases; films also restrict heat transfer, which retards the rate of cooling (Hardenburg 1971).

Waxes are applied to rutabagas, cucumbers, mature green tomatoes, and cantaloupes, and to a lesser extent to peppers, turnips, sweet potatoes, and certain other crops. With products such as cucumbers and root crops, waxing reduces moisture loss and thus retards shriveling. With some products, an improved glossy appearance is the main advantage. Thin wax coatings may give little if any protection against moisture loss; coatings that are too heavy may increase decay and breakdown. Waxing alone does not control decay, but waxing combined with fungicides may be beneficial. Waxing is not recommended for potatoes either before or after storage (Hardenburg et al. 1959).

IN-TRANSIT PRESERVATION

Good equipment is available to transport perishable commodities to market under refrigeration by rail, trucks, piggyback trailers, and containers. A high relative humidity (rh) of about 95% is desirable for most vegetables to prevent moisture loss and wilting. Many

vegetables benefit from 95 to 100% rh. Humidity in both iced and mechanically refrigerated cars and trailers is usually high.

Cooling Vehicle and Product

Vehicles used to ship vegetables that require low temperatures during transit should have their interiors cooled before loading to prevent produce loaded near container walls from warming under hot ambient conditions or cooling too much under cold ambient conditions. In temperate climates with low humidity, the container should be cooled to the carrying temperature. If loading from an open dock in a humid environment, the container should be cooled to the dew point of the outside air. Temperatures below the dew point cause water to condense on walls, which may damage fiberboard packages. In all cases, the refrigeration should be turned off when the container doors are open. This prevents moisture from condensing on the evaporator coils.

Generally, vegetables that require a low temperature during shipping should be cooled before they are loaded into transport vehicles. Cooling produce in tightly loaded refrigerator cars or containers is a slow process, and the portion of the load exposed to the cold air discharge may be frozen when the interior of the load is still warm. Highway trailers do not have adequate airflow to remove field heat from perishable produce.

Packaging, Loading, and Handling

In this section, the term “boxes” is used for corrugated containers and “containers” is used for marine containers. Boxes must protect the commodity, permit heat exchange as necessary, and serve as an appropriate merchandising unit with sufficient strength to withstand normal handling. Freight container tariffs describe approved containers and loading procedures.

Boxes should be loaded to take advantage of their maximum strength and to permit adequate stripping, or use of spacers to hold the load in alignment. Proper vertical alignment of containers is essential to obtain their maximum stacking strength. Previously, when boxes were hand-stacked, stacks were spaced to provide channels for air circulation. Air channels are no longer specified with the use of pallet loads.

When different types of boxes are used in the same load, stacks should be separated so that one type will not damage another. If separation of stacks is impossible, boxes made of lighter material, such as fiberboard, should always be loaded on top of heavier wood boxes.

Providing Refrigeration and Air Circulation

Safe transit temperatures for various vegetables and suggested temperatures for refrigerated transport vehicles are given in [Table 2](#). For safety, the suggested thermostat settings for cool-season vegetables are usually 1 to 2 K above the freezing point.

Perishables are often shipped in loads with other commodities. When this occurs, the loads should be set up so that different types of produce have compatible temperature ranges and ethylene sensitivities. Use [Table 2](#), which groups common fruits and vegetables by temperature range and ethylene sensitivity, to select compatible produce. Produce in the same column can be safely held at the same temperature range. Mixing produce from different temperature ranges can compromise produce quality, especially with longer transit times. The greater the difference in recommended temperatures, the greater the potential for quality loss.

Dry vegetables (row 1 of [Table 1](#)) should not be mixed with any other produce in the table. These vegetables should be held in a 50 to 70% rh environment to prevent decay. Most of the vegetables in the lowest temperature range (0 to 2°C) are sensitive to moisture loss and should be held at more than 90% rh or packaged to minimize water loss. The other vegetables and fruit should be held at 85 to 95% rh.

Table 1 Compatible Produce for Long-Distance Transport

Produce	Recommended Storage Temperatures				
	0 to 2°C		4 to 7°C	7 to 10°C	13 to 18°C
Dry vegetables	Dry onion ^{1,3,9}	Garlic			Ginger ⁵ Pumpkin Squash, winter
Ethylene-sensitive vegetables	Arugula ^a Asparagus Belgian endive Bok choy Broccoflower Broccoli ^a Brussels sprouts Cabbage ¹ Carrot ^{1,3} Cauliflower Celery ^{1,3,9} Chard ^a	Chicory Chinese cabbage Collards ^a Cut vegetables Endive Escarole Green onion ⁷ Herbs (not basil) Kailan ^a Kale ^a Leek ⁸ Lettuce	Mint Mushroom ^{a,7} Mustard greens ^a Parsley Parsnip Snow pea ^a Spinach ^a Sweet pea ^a Turnip greens Watercress	Beans, snap, etc. ^{a,10} Cactus leaves Cucumber ^a Pepper (chili) Potato, late crop ¹ Southern peas ^a Tomatillo	Basil ^a Chayote Eggplant ^{a,5} Kiwano Long bean Okra Squash, summer ^a Watermelon
Vegetables (not ethylene sensitive)	Amaranth ^a Anise Artichoke Bean sprouts ^a Beet Celeriac Daikon Horseradish	Jerusalem artichoke Kohlrabi Lo bok Radicchio Radish Rhubarb ⁷ Rutabaga	Salsify Scorzonera Shallot Sweet corn ⁷ Swiss chard Turnip Water chestnut		Calabaza Haricot vert Pepper, bell ¹⁰ Winged bean Luffa ^{a,b}
Fruits and melons (very low ethylene producing)	Barbados cherry Bitter melon Blackberry ^a Blueberry Caimito Cashew apple Cherry Coconut Currant Date Gooseberry Grape ^{6,7,8}	Longan Loquat Lychee Orange, FL ⁴ Raspberry ^a Strawberry ^a	Blood orange ⁴ Cactus pear (tuna) Jujube Kumquat Mandarin ⁴ Olive Orange, CA, AZ ⁴ Pepino Persimmon Pomegranate Tamarind Tangerine ⁴	Babaco Calamondin ^a Carambola Casaba melon Cranberry Grapefruit ⁴ Juan Canary melon Lemon ⁴ Lime ⁴ Pineapple ^{2,10} Pummelo ⁴	Breadfruit Canistel Grapefruit, CA, AZ ⁴ Jaboticaba ^a
Ethylene-producing fruits and melons	Apple ^{1,3,9} Apricot Avocado, ripe Cantaloupe Cut fruits Fig ^{1,7,8} Kiwifruit Nectarine Peach Pear, Asian Pear, European ^{1,9}	Plum Prune Quince	Durian Feijoa Guava Honeydew melon Persian melon	Avocado, unripe Crenshaw melon Custard apple Passion fruit	Atemoya Banana Cherimoya Jackfruit Mamey Mango Mangosteen Papaya Plantain Rambutan Sapote Soursop ^a

Source: University of California (1997). Reprinted with permission.

Note: Produce in the same temperature column can be safely mixed. Ethylene-sensitive vegetables should not be mixed with ethylene-producing fruits and vegetables. Dry vegetables should not be mixed with other fruits and vegetables.

^aLess than 14 day shelf life at recommended temperature and normal atmosphere conditions.

^bProduces moderate amounts of ethylene and should be treated as an ethylene-producing fruit.

1. Odors from apples and pears are absorbed by cabbage, carrots, celery, figs, onions, and potatoes.

2. Avocado odor is absorbed by pineapple.

3. Celery absorbs odor from onions, apples, and carrots.

4. Citrus absorbs odor from strongly scented fruits and vegetables.

5. Ginger odor is absorbed by eggplant.

6. Sulfur dioxide released from pads used with table grapes will damage other produce.

7. Green onion odor is absorbed by figs, grapes, mushrooms, rhubarb, and corn.

8. Leek odor is absorbed by figs and grapes.

9. Onion odor is absorbed by apples, celery, and citrus.

10. Pepper odor is absorbed by beans, pineapples, and avocados.

Ethylene-sensitive vegetables (row 2) should not be mixed with ethylene-producing fruits (row 5). If, for some reason, they must be mixed, damage may be reduced by using a fresh air exchange rate of 20 L/s (Thompson et al. 2000) and/or ethylene scrubbers. In some cases, a controlled atmosphere (CA) will allow ethylene-sensitive produce to be shipped with ethylene-producing produce, but the acceptable produce combinations and atmosphere prescriptions are not well documented. Produce that is neither ethylene sensitive nor ethylene producing (rows 3 and 4) can be mixed with produce above or below them in the same temperature column.

Some produce items can exchange odors with other items. See the notes at the bottom of [Table 1](#) for precautions.

Certain produce items have a short postharvest life and are not suited for container shipments, especially if held at nonoptimal

temperatures. For example, asparagus has a maximum postharvest life of 3 weeks if held at 2.5°C. If shipped at 0°C in a load of broccoli, it will be subject to chilling injury after only 10 days. Modified atmosphere (MA) packaging can sometimes be used to increase produce life and allow shipping to destinations that require several weeks' transport time. If a CA environment is used, it should, at a minimum, not reduce the postharvest life of any of the mixed commodities.

[Table 1](#) is also applicable to the fruits covered in [Chapter 21](#).

With the many kinds of refrigeration, heating, and ventilating services now available, the shipper has only to specify the desired transport temperature. Generally, the shipper or the receiver is responsible for selecting the protective service for the commodity in transit. The various protective services are described in detail in Ashby et al. (1995).

Protection from Cold

During the winter, vegetables must be protected from freezing. Refrigerated transport vehicles, equipped to handle the full range of both fresh and frozen commodities, are also designed to provide heat for cold weather protection. The heat is supplied by electric heating elements or by reverse-cycle operation of the refrigerating unit (hot gas from the compressor is circulated in the cooling coils). The change from cooling to heating is done automatically by thermostatic controls.

In-transit freezing is a major problem in moving late crop potatoes from storage to market. Cars and trailers should be warmed before loading, protected during loading with canvas door shields or loading tunnels, and loaded properly.

Checking and Cleaning Equipment

If the thermostat is out of adjustment by a few degrees, products may be damaged by freezing or by insufficient refrigeration. Thermostats should be calibrated at regular intervals to ensure that the proper amount of refrigeration is furnished. Trailers and railcars should be cleaned carefully before loading. Debris from previous shipments may contaminate loads and should be swept from floors and floor racks.

Modified Atmospheres in Transit

A variety of systems provide controlled or modified atmospheres in railcars and marine containers. Although the gas concentration for each process may differ, all systems alter the levels of O₂, CO₂, and nitrogen surrounding the produce.

The O₂ concentration in air is usually lowered to 1 to 5% because this level tends to depress the respiration rate.

No single modified atmosphere can be expected to benefit more than a few commodities; crop requirements and tolerances are quite specific (see [Table 1 in Chapter 10](#)). Also, certain vegetables may tolerate an atmosphere at one temperature but not at another, or they may tolerate a modified atmosphere for only a limited time.

The load compartment must be fairly tight to maintain desired atmospheres. Modified atmosphere equipment is predominantly installed in vehicles used to transport chilled perishables in long-haul movements (over five days' transit time). Atmosphere systems used in transport either vaporize liquid nitrogen or generate nitrogen by passing heated compressed air through hollow fibers.

Temperature is critical in determining the benefits of modified atmospheres. If temperatures are higher than recommended, increased respiration will lower O₂ and raise CO₂ levels toward anaerobic levels. In addition, decay and other deterioration may be increased rather than reduced. Modified atmospheres should never be used as a substitute for good temperature management.

Use of controlled atmospheres is discussed later in this chapter. For further information on refrigerated transport by truck, ship, and air, see [Chapters 29 through 31](#).

Table 2 Optimal Transit Temperatures for Various Vegetables

Vegetable	Desirable Transit Temperature, °C	Suggested Thermostat Setting, ^a °C	Highest Freezing Point, ^b °C
Artichokes	0	0.6	-1.2
Asparagus	0 to 2	1.7	-0.6
Beans, lima	3 to 5	3	-0.6
Beans, snap	4 to 7	7	-0.7
Beets, topped	0	1	-0.9
Broccoli	0	1	-0.6
Brussels sprouts	0	1	-0.8
Cabbage	0	1	-0.9
Cantaloupes	2 to 5	3	-1.2
Carrots, topped	0	0.6	-1.4
Cauliflower	0	1	-0.8
Celery	0	1	-0.5
Corn, sweet	0	1	-0.6
Cucumbers	10 to 13	10	-0.5
Eggplant	8 to 12	10	-0.8
Endive and escarole	0	1	-0.1
Greens, leafy	0	1	—
Honeydew melon	7 to 10	7	-0.9
Lettuce	0	1	-0.2
Onions, dry	0 to 4	1.7	-0.8
Onions, green	0	1	-0.9
Peas, green	0	1	-0.6
Peppers, sweet	7 to 10	8	-0.7
Potatoes:			
Early crop	10 to 16	10	-0.6
Late crop	4 to 10	4.4	-0.6
For chipping:			
Early crop	18 to 21	18 to 21	-0.6
Late crop	10 to 16	10 to 16	-0.6
Radishes	0	1	-0.7
Spinach	0	1	-0.3
Squash, summer	5 to 10	5	-0.6
Squash, winter	10 to 13	10	-0.8
Sweet potatoes	13 to 16	13	-1.3
Tomatoes:			
Mature green	13 to 21	13	-0.6
Pink	10	10	-0.8
Watermelons	10 to 16	10	-0.4

Sources: USDA *Agricultural Handbook* No. 195 (Redit 1969), USDA *Marketing Research Report* No. 196 (Whiteman 1957), and USDA *Agricultural Handbook* No. 66 (Hardenburg et al. 1986).

^aFor U.S. shipments of vegetables in mechanically refrigerated cars under Rule 710 and in trailers under Rule 800 of the Perishable Protective Tariff.

^bHighest temperature at which freezing occurs.

**Table 3 Compatible Fresh Fruits and Vegetables During 7 Day Storage
Wholesale and Retail Handling Operations**

Produce	Group 1			Group 2		Group 3	
	0 to 2°C and 90 to 98% rh			7 to 10°C and 85 to 95% rh		16 to 18°C and 85 to 95% rh	
Vegetables	Alfalfa sprouts	Chinese cabbage	Mint	Basil		Bitter melon	
	Amaranth	Chinese turnip	Mushroom	Beans; snap, green, wax		Boniato	
	Anise	Collards*	Mustard greens*	Cactus leaves (nopales)		Cassava	
	Artichoke	Corn; sweet, baby	Parsley*	Calabaza		Dry onion	
	Arugula*	Cut vegetables	Parsnip	Chayote*		Ginger	
	Asparagus*	Daikon*	Radicchio	Cowpea (Southern pea)		Jicama	
	Beans; fava, lima	Endive*-chicory	Radish	Cucumber*		Potato	
	Bean sprouts	Escarole*	Rutabaga	Eggplant*		Pumpkin	
	Beet	Fennel	Rhubarb	Kiwano (horned melon)		Squash; winter (hard rind)*	
	Belgian endive*	Garlic	Salsify	Long bean		Sweet potato*	
	Bok choy	Green onion*	Shallot	Malanga		Taro (dasheen)	
	Broccoli*	Herbs* (not basil)	Spinach*	Okra*		Tomato; ripe, partially ripe, mature green	
	Broccoflower*	Horseradish	Scorzonera	Pepper; bell, chili		Yam*	
	Brussel sprouts*	Jerusalem	Snow pea*	Squash; summer (soft rind)*			
	Cabbage*	artichoke	Sweet pea*	Tomatillo			
	Carrot*	Kale	Swiss chard	Winged bean			
	Cauliflower*	Kailon	Turnip				
	Celeriac	Kohlrabi	Turnip greens*				
	Celery*	Leek*	Water chestnut				
	Chard*	Lettuce*	Watercress*				
Fruits and Melons	Apple	Elderberry	Prune	Avocado, unripe	Lime*	Atemoya	Rambutan
	Apricot	Fig	Quince	Babaco	Limequat	Banana	Sapodilla
	Avocado, ripe	Gooseberry	Raspberry	Cactus pear, tuna	Mandarin	Breadfruit	Sapote
	Barbados cherry	Grape	Strawberry	Calamondin	Olive	Canistel	Soursop
	Blackberry	Kiwifruit*		Carambola	Orange	Casaba melon	
	Blueberry	Loganberry		Cranberry	Passion fruit	Cherimoya	
	Boysenberry	Longan		Custard apple	Pepino	Crenshaw melon	
	Caimito	Loquat		Durian	Pineapple	Jaboticaba	
	Cantaloupe	Lychee		Feijoa	Pummelo	Jackfruit	
	Cashew apple	Nectarine		Granadilla	Sugar apple	Honeydew melon	
	Cherry	Peach		Grapefruit*	Tamarillo	Mamey	
	Coconut	Pear; Asian, European		Guava	Tamarind	Mango	
	Currant	Persimmon*		Juan Canary	Tangelo	Mangosteen	
	Cut fruits	Plumcot		melon	Tangerine	Papaya	
	Date	Plum		Kumquat	Ugli fruit	Persian melon	
	Dewberry	Pomegranate		Lemon*	Watermelon*	Plantain	

Source: University of California (1997). Reprinted with permission.

Note: Ethylene level should be kept below 1 mg/kg in all storage areas.

*Products marked with an asterisk are sensitive to ethylene damage.

PRESERVATION IN DESTINATION FACILITIES

Wholesale warehouse facilities usually do not have a wide range of controlled temperature rooms to provide optimum storage conditions for each kind of produce, and this is not necessary for short holding. It is, however, necessary to separate products into groupings by temperature and humidity. Table 3 groups fruits and vegetables into three temperature groups, and the low-temperature group is subdivided into two humidity groups. This allows a convenient number of storage conditions for distribution centers, retail stores, and food service operations. Group 1, at 0 to 2°C, includes the majority of produce volume in most North American food-handling operations. Group 1A has the vegetables, many of which are wilting- and ethylene-sensitive, and 1B has the low-temperature fruits that rarely need high humidity and mostly do not produce ethylene. Group 2, at 7 to 10°C, has citrus and subtropical fruits and many fruit vegetables. Group 3, at 16 to 18°C, has some common root vegetables, winter (hard-rind) squashes, and most of the tropical fruits and melons. Group 3 conditions are also used for ripening products such as pears and stone fruit.

Distribution centers should have separate cold rooms for each of the four combinations of temperature and humidity. Groups 1A and 1B can be combined if only three rooms are available, but fruits and

vegetables should be separated in the room. Retail stores rarely have three temperature-controlled rooms; Group 3 products can be held in an air-conditioned corridor or preparation room.

Ethylene must be kept below 1 mg/kg in all storage rooms, particularly in Group 1A, which holds most of the ethylene-sensitive produce. Ethylene can be kept low by separating storage rooms, night outside ventilation, and ethylene-absorbing equipment. Operators should consider the use of air curtains, flap doors, or other infiltration reduction devices whenever doors to cold rooms must be opened often or for prolonged periods.

Mature green tomatoes (for ripening) usually need separate, temperature-controlled rooms where 13 to 21°C temperatures with 85 to 90% rh can be maintained to delay or speed ripening as desired.

REFRIGERATED STORAGE CONSIDERATIONS

The refrigeration requirement of any storage facility must be based on peak refrigeration load. This peak usually occurs when outside temperatures are high and warm produce is being moved into the plant for cooling and storage. The peak refrigeration load depends on the amount of commodity received each day, the temperature of the commodity at the time it is placed under refrigeration, the specific heat of the commodity, and the final tempera-

ture attained. Information on general aspects of cold storage design and operation can be found in [Chapters 10, 12, and 13](#).

Sprout Inhibitors

Sprout inhibitors are used when cold storage facilities are lacking or if low temperatures might injure the vegetable or affect its processing quality. In-storage sprouting of onions, potatoes, and carrots can be inhibited by spraying the plants a few weeks before harvest with a solution of maleic hydrazide. Potatoes are also sprayed or dipped in a solution that inhibits sprouting. Vaporized nonanol alcohol is circulated through ducts to suppress potato sprouting in Great Britain (Burton 1958).

Gamma irradiation suppresses sprouting of onions, sweet potatoes, and white potatoes at dosages of 0.05 to 0.15 kGy. Dosages above 0.15 kGy cause breakdown and increased decay in white potatoes (Kader et al. 1984).

Controlled and Modified Atmosphere Storage

Refrigeration is most effective in retarding respiration and lengthening storage life. For some products, reducing the O₂ level in the storage air and/or increasing the CO₂ level as a supplement to refrigeration can provide extended storage life. Careful control of the concentration of O₂ and CO₂ is essential. If all of the O₂ is used, produce will suffocate and may develop an alcoholic off-flavor in a few days. CO₂ given off in respiration or from dry ice may accumulate to injurious levels.

CA storage usually uses external generators, or nitrogen or dry ice, to create desired atmospheres rather than using product respiration in a gastight room. MA packaging, on the other hand, can obtain its gas concentrations either by initial flushing of the package (usually polyethylene) or by product respiration, which reaches equilibrium concentrations within a few days in cold storage. More rapid equilibration is accomplished by minimizing the initial air volume in the package, or by starting with warm product in the package prior to cold storage. Polyethylene packaging is useful because it transmits CO₂ about 5 times as readily as it transmits O₂. This permits low (5%) O₂ levels to prevail with low CO₂ levels (2 to 3%), preventing injury. If higher CO₂ levels are desirable, then MA packaging accomplished by pinholes should be used, because holes transfer both gases equally well. Pinholes, however, have no temperature forgiveness: they transmit at the same rate even if refrigeration is lost, which leads to anaerobic conditions (very low O₂, high CO₂) in the package. Polyethylene is more forgiving of temperature abuse because its gas transmission rate increases with temperature (doubles with a 39.6 K rise), although the increase is less than that of respiration (doubles with a 16.2 K rise). MA packaging preserves product by lowering its respiration rate and, equally important, by retaining its moisture with 95 to 100% rh in the package. Again, MA packaging due to pinholes can cause excessive in-package condensate problems because, although the holes can transmit adequate O₂, they transmit much less water vapor than large permeable polyethylene surfaces (Moyle et al. 1998).

[Table 1 in Chapter 10](#) provides a listing of CA and MA requirements and recommendations.

Hypobaric storage, or storage at reduced atmospheric pressure, is another supplement to refrigeration that involves principles similar to those in controlled-atmosphere storage. At atmospheric pressures 0.1 or 0.2 of normal, several kinds of produce have an extended storage life. The benefits are attributed both to the low O₂ level maintained and to the continuous removal of ethylene, CO₂, and possibly other metabolically active gases. Their rates of production under hypobaric ventilation are also lower.

Positive hypobaric ventilation is required to achieve the desired low ethylene concentration within and around produce to retard ripening. The continuous flow of water-saturated air at a low pressure flushes away emanated gases and prevents loss of mass.

Despite benefits, the costs of hypobaric storage structures are not commercially viable.

Table 4 Vegetables Susceptible to Chilling Injury at Moderately Low but Nonfreezing Temperatures

Commodity	Approximate Lowest Safe Temperature, °C	Character of Injury Between 0°C and Safe Temperature ^a
Beans (snap)	7	Pitting and russetting
Cucumbers	10	Pitting; water-soaked spots, decay
Eggplants	7	Surface scald; <i>Alternaria</i> rot
Melons:		
Cantaloupes	a	Pitting; surface decay
Honeydew	7 to 10	Pitting; failure to ripen
Casaba	7 to 10	Pitting; surface decay
Crenshaw and Persian	7 to 10	Pitting; surface decay
Watermelons	4	Pitting; objectionable flavor
Okra	7	Discoloration; water-soaked areas; pitting; decay
Peppers, sweet	7	Sheet pitting, <i>Alternaria</i> rot on pods and calyxes
Potatoes	3 to 4	Mahogany browning (Chippewa and Sebago); sweetening ^b
Pumpkins and hard-shell squash	10	Decay, especially <i>Alternaria</i> rot
Sweet potatoes	13	Decay; pitting; internal discoloration
Tomatoes:		
Ripe	10 ^a	Water-soaking and softening; decay
Mature green	13	Poor color when ripe; <i>Alternaria</i> rot

Sources: From USDA *Agricultural Handbook* No. 66 (Hardenburg et al. 1986).

^aSee text.

^bOften these symptoms appear only after removal to warm temperatures, as in marketing.

Injury

Chilling injury may be defined as an injury caused by exposure to low but nonfreezing temperatures, often between 0 to 10°C. At these temperatures, vegetables are weakened because they are unable to carry on normal metabolic processes. Often, vegetables that are chilled look sound when removed from low temperatures. However, symptoms of chilling (pitting or other skin blemishes, internal discoloration, or failure to ripen) become evident in a few days at warmer temperatures (Morris and Platenius 1938). Vegetables that have been chilled may be particularly susceptible to decay. *Alternaria* rot is often severe on tomatoes, squash, peppers, and cantaloupes that have been chilled. Tomatoes that have been severely chilled usually ripen slowly and rot rapidly.

Both time and temperature are involved in chilling injury. Damage may occur in a short time if temperatures are considerably below the safe storage temperatures, but a product may withstand a few degrees in the danger zone for a longer time. Also, the effects of chilling are cumulative. Low temperatures in the field before harvest, in transit, and in storage all contribute to the total effects of chilling. A list of vegetables susceptible to chilling injury together with the symptoms and the lowest safe temperatures are shown in [Table 4](#).

[Table 2](#) shows the **freezing points** of various vegetables. The freezing point is the highest temperature at which ice crystal formation in the tissues has been recorded experimentally. Most vegetables have a freezing point between -2.2 to -0.6°C (Whiteman 1957). Different vegetables vary widely in their susceptibility to freezing injury.

Tissues injured by freezing generally appear water-soaked. Even though some vegetables are somewhat tolerant of freezing, it is desirable to avoid freezing temperatures because they shorten storage life (Parsons and Day 1970).

To minimize damage, fresh commodities should not be handled while frozen. Fast thawing damages tissues, but very slow thawing

(0 to 1°C), permits ice to remain in the tissues too long. Thawing at 4°C is suggested (Lutz 1936).

STORAGE OF VARIOUS VEGETABLES

In the following sections, the temperatures and relative humidity recommendations (shown in parentheses) are the optimum for maximum storage in the fresh condition. For short storage, higher temperatures may be satisfactory for some commodities. Temperature requirements represent commodity temperatures that should be maintained. Much of this information is taken from USDA *Agricultural Handbook* No. 66 (Hardenburg et al. 1986).

The quality of each lot of produce should be determined at the time of storage, and regular inspections should be made during storage. Such vigilance will permit early detection of disease so that the affected commodity can be moved out of storage before serious loss occurs.

Artichokes, Globe (0°C and 95 to 100% rh)

Globe artichokes are seldom stored, but for temporary holding a temperature of about 0°C is recommended. A high relative humidity (at least 95%) will help prevent wilting. This product should keep for 2 weeks in storage if buds are uninjured and wilting is prevented. Perforated polyethylene liners with 250 6 mm holes/m² help retard moisture loss. Hydrocooling or room cooling to 4°C on the day of harvest reduces deterioration.

Gray Mold Rot (*Botrytis*). The most common decay of harvested artichokes. Reddish brown to dark brown firm rot (See [Table 5](#), Note 2). *Control:* Practice sanitation in the field. Refrigerate promptly.

Asparagus (0 to 2°C and 95 to 100% rh)

Asparagus deteriorates very rapidly at temperatures above 2°C and especially at room temperature. It loses sweetness, tenderness, and flavor, and decay develops later. If the storage period is 10 days or less, 0°C is recommended; asparagus is subject to chilling injury if held longer at this temperature. Asparagus is not ordinarily stored except temporarily, but at 2°C with a high relative humidity, it can be kept in salable condition for 3 weeks. However, after a long haul to market, even under refrigeration, it cannot be expected to keep longer than 1 to 2 weeks.

Asparagus should be cooled immediately after cutting. Hydrocooling is the usual method. During transit or storage, the butts of asparagus should be placed on some moist absorbent material to prevent loss of moisture and to maintain freshness of the spears. Sometimes asparagus bunches are set in shallow pans of water in storage.

Bacterial Soft Rot. Mushy, soft, watersoaked areas on tips and cut ends of asparagus (see [Table 5](#), Note 1). *Control:* Avoid excessive bruising of tips; cool to 4°C.

Fusarium Rot. Watersoaked areas changing through yellow to brown, chiefly on asparagus tips; white to pink delicate mold. *Control:* Cool and ship at temperatures of 4°C or lower; handle promptly. Keep tips dry on way to market.

Phytophthora Rot. Large, watersoaked, or brownish lesions at the side of cut asparagus stalks. Lesions later are extensively shriveled. *Control:* Cool to 4°C. Maintain low transit temperatures. Market promptly.

Beans, Green or Snap (4 to 7°C and 95% rh)

Green or snap beans are probably best stored at 4 to 7°C, where they may keep for about 1 week. Even these recommended temperatures cause some chilling injury, but are best for short storage. When stored at 4°C or below for 3 to 6 days, surface pitting and russet discoloration may appear in a day or two following removal for marketing. The russetting will be especially noticeable in the centers of the containers where condensed moisture remains. *Contact icing is not recommended.* To prevent wilting, the relative humidity should be maintained at 90 to 95%. Beans for processing can be stored up to 10 days at 4°C. Containers of beans should be stacked

Table 5 Notes on Diseases of General Occurrence

Note 1. Bacterial Soft Rot

Occurs on various vegetables as dark green, greasy or watersoaked soft spots and areas in leaves and stems. Soft, mushy, yellowish spots or soupy areas on stems, roots, and tubers of vegetables. Frequently accompanied by repulsive odor from secondary invaders. *Control:* Use sanitation practices during picking and packing to reduce contamination of harvested product. Use bactericides in postharvest wash treatments. Where possible avoid bruising and injury. Shade harvested produce in the field and reduce temperature promptly to 4°C or lower for commodities that can withstand low temperatures.

Note 2. Gray Mold Rot (*Botrytis*)

Decayed tissues are fairly firm to semiwatery. Watersoaked grayish tan to brownish in color. Gray mold and grayish brown, with conspicuous velvety spore masses. *Control:* Use sanitation practices during harvesting and packing. Avoid wounds as much as possible. Use storage and transit temperatures as low as otherwise practicable because decay progresses even at 0°C.

Note 3. Rhizopus Rot

Decayed tissues are watersoaked, leaky, and softer than those with gray mold rot or watery soft rot. Coarse mycelium and black spore heads develop under moist conditions. Nesting is common. *Control:* Insofar as possible, avoid injury and bruising. Reduce temperature promptly and maintain below 10°C for commodities that can withstand low temperatures.

Note 4. Watery Soft Rot (*Sclerotinia*)

Decayed tissues are watersoaked, with slightly pinkish or brownish tan borders; very soft and watery in later stages, accompanied by development of fine white to dingy cottony mold and black to brown mustard seed-like bodies called *sclerotia*. Nesting is common. *Control:* Use sanitary practices in harvesting and packing. Cull out specimens with discolored or dead portions. Maintain temperature as low as practicable because rot progresses even at 0°C. Do not store commodities known to have watery soft rot at harvest time.

to allow abundant air circulation; otherwise, the temperature may rise from the heat of respiration. Beans stored too long or at too high a temperature are subject to such decays as watery soft rot, slimy soft rot, and rhizopus rot.

Anthracnose (*Colletotrichum*). Circular or oval sunken spots; reddish brown around border with tan centers that frequently bear pink spore mounds. *Control:* Use resistant varieties. Plant disease-free seed. Refrigerate harvested beans promptly to 7°C.

Bacterial Blight (*Pseudomonas*). Small, greasy-appearing, watersoaked spots in pod. Older spots show red at the center, with watersoaked area surrounding and penetrating to the seed. *Control:* Keep the field sanitary. Use disease-free seed. Reduce the transit temperature promptly to 7°C.

Bacterial Soft Rot. See [Table 5](#), Note 1.

Cottony Leak (*Pythium*). Pods with large, watersoaked spots, accompanied by abundant white cottony mold. *Control:* Sort out diseased pods in packing. Reduce transit temperature promptly to 7°C.

Freezing Injury. Slight freezing results in watersoaked mottling on surface of exposed pods. Severely frozen beans become completely watersoaked, limp, and dry out rapidly. Snap beans freeze at about -0.5°C.

Russetting. Chestnut brown or rusty, diffuse surface discoloration on both sides of pods. *Control:* Permit no surface moisture on warm beans. Cool promptly; avoid temperatures lower than 7°C.

Soil Rot (*Rhizoctonia*). Large, reddish brown, sunken, decayed spots on pods. Cream-colored or brown mycelium and irregular chocolate-colored sclerotia may develop. Nesting is common. *Control:* Maintain transit temperatures of 7 to 10°C.

Watery Soft Rot. Presence of large black sclerotia in white mold helps to separate this from cottony leak (see [Table 5](#), Note 4).

Beans, Lima (3 to 5°C and 95% rh)

For best quality, lima beans should not be stored. Unshelled lima beans can be stored for about 1 week at 3 to 5°C. They should be used promptly after removal because the pods discolor rapidly at room temperature. Even with only 1 week of refrigerated storage, the pods may develop rusty brown or brown specks, spots, and larger discolored areas that reduce salability of the beans. The pod discoloration will increase sharply during an additional day at 21°C following storage.

Beets (0°C and 98 to 100% rh)

Topped beets are subject to wilting because of the rapid loss of water when the storage atmosphere is too dry. When stored at 0°C with at least 95% rh, they should keep for 4 to 6 months. Before beets are stored, they should be topped and sorted to remove all beets that are diseased and showing mechanical injury. Bunch beets under the same conditions will keep 1 to 2 weeks. Contact icing is recommended. The containers should be well ventilated and stacked to allow air circulation.

Bacterial Soft Rot. See [Table 5](#), Note 1.

Broccoli (0°C and 95 to 100% rh)

Italian or sprouting broccoli is highly perishable and is usually stored for only a brief period as needed for orderly marketing. Good salable condition, fresh green color, and vitamin C content are best maintained at 0°C. If it is in good condition and is stored with adequate air circulation and spacing between containers to avoid heating, broccoli should keep satisfactorily 10 to 14 days at 0°C. Longer storage is undesirable because leaves discolor, buds may drop off, and tissues soften. The respiration rate of freshly harvested broccoli is high comparable to that of asparagus, beans, and sweet corn. This high rate of respiration should be considered when storing broccoli, especially if it is held without package ice.

Brussels Sprouts (0°C and 95 to 100% rh)

Brussels sprouts can be stored in good condition for a maximum of 3 to 5 weeks at the recommended temperature of 0°C. Deterioration, yellowing of the sprouts, and discoloration of the stem are rapid at temperatures of 10°C and above. Rate of deterioration is twice as fast at 4°C as at 0°C. Loss of moisture through transpiration is rather high even if the relative humidity is kept at the recommended level. Film packaging is useful in preventing moisture loss. As with broccoli, sufficient air circulation and spacing between packages is desirable to allow good cooling and to prevent yellowing and decay.

Cabbage (0°C and 98 to 100% rh)

A large percentage of the late crop of cabbage is stored and sold during the winter and early spring, or until the new crop from southern states appears on the market. If it is stored under proper conditions, late cabbage should keep for 3 to 4 months. The longest-keeping varieties belong to the Danish class. Early crop cabbage, especially southern grown, has a limited storage life of 3 to 6 weeks.

Cabbage is successfully held in common storage in northern states, where a fairly uniform inside temperature of 0 to 2°C is maintained. An increasing quantity of cabbage is now held in mechanically refrigerated storage, but in some seasons its value does not justify the expense. Use of controlled atmospheres to supplement refrigeration aids quality retention. An atmosphere with 2.5 to 5% O₂ and 2.5 to 5% CO₂ can extend the storage life of late cabbage. Cabbage should not be stored with fruits emitting ethylene. Concentrations of 10 to 100 mg/kg of ethylene cause leaf abscission and loss of green color within 5 weeks at 0°C.

Pallet bins are used as both field and storage containers, so the cabbage requires no handling from the time of harvest until preparation for shipment. Before the heads are stored, all loose leaves

should be trimmed away; only 3 to 6 tight wrapper leaves should be left on the head. Loose leaves interfere with ventilation between heads, which is essential for successful storage. When removed from storage, the heads should be trimmed again to remove loose and damaged leaves.

Chinese cabbage can be stored for 2 to 3 months at 0°C with 95 to 100% rh.

Alternaria Leaf Spot. Small to large spots bearing brown to black mold. This spotting opens the way for other decays. *Control:* Avoid injuries. Maintain 0 to 1°C temperature in transit and storage. Practice sanitation in storage rooms.

Bacterial Soft Rot. This slimy decay frequently starts in the pith of a cut stem or in leaf spots caused by other organisms (see [Table 5](#), Note 1).

Black Leaf Speck. Small, sharply sunken, brown or black specks occurring anywhere on outer leaves or on leaves throughout the head. Occurs under refrigeration in transit and storage, and in association with sharp temperature drops. *Control:* No effective control measures are known.

Freezing Injury. Heads frozen slightly may thaw without apparent injury. Freezing injury first appears as brown streaks in the stem, then as light brown watersoaking of the heart leaves and stem. *Control:* Prevent any extended exposure to temperatures below -0.5°C.

Watery Soft Rot. See [Table 5](#), Note 4.

Carrots (0°C and 98 to 100% rh)

Carrots are best stored at 0°C with a very high relative humidity. Like beets, they are subject to rapid wilting if the humidity is low. For long storage, carrots should be topped and free from cuts and bruises. If they are in good condition when stored and promptly cooled after harvest, mature carrots should keep 5 to 9 months. Carrots lose moisture readily and wilting results. Humidity should be kept high, but condensation or dripping on the carrots should be avoided, since this causes decay.

Most carrots for the fresh market are not fully mature. Immature carrots are prepackaged in polyethylene bags either at the shipping point or in terminal markets. They are usually moved into marketing channels soon after harvest, but they can be stored for a short period to avoid a market glut. If the carrots are cooled quickly and all traces of leaf growth are removed, they can be held 4 to 6 weeks at 0°C.

In Texas, immature carrots are often stored in clean 23 kg burlap sacks. The sacks of carrots should be stacked in such a manner that at least one surface of each sack is in contact with top ice at all times. Top ice provides some of the necessary refrigeration and prevents dehydration. Bunched carrots may be stored 10 to 14 days at 0°C. Contact icing is recommended.

Bitterness in carrots, which may develop in storage, is due to abnormal metabolism caused by the ethylene emitted by apples, pears, and some other fruits and vegetables. It can also be caused by other sources such as internal combustion engines. Bitterness can be prevented by storing carrots away from products that give off ethylene.

Bacterial Soft Rot. See [Table 5](#), Note 1.

Black Rot (*Stemphylium*). Fairly firm black decay at the crown, on the side, or at the tips of harvested roots. *Control:* Avoid bruising. Store at 0°C.

Crater Rot (*Rhizoctonia*). Circular brown craters with white to cream-colored mold in the center. Develops under high humidity in cold storage. *Control:* Field sanitation measures. Avoid surface moisture on storage roots.

Freezing Injury. Roots are flabby and on cutting show radial cracks in the flesh of the central part and tangential cracks in the outer part. *Control:* Prevent exposure to temperatures below -1°C.

Gray Mold Rot. See [Table 5](#), Note 2.

Rhizopus Rot. See [Table 5](#), Note 3.

Watery Soft Rot. See [Table 5](#), Note 4.

Cauliflower (0°C and 95% rh)

Cauliflower may be stored for 3 to 4 weeks at 0°C with about 95% rh. Successful storage depends on retarding the aging of the head or curd, preventing decay marked by spotting or watersoaking of the white curd, and preventing yellowing and dropping of the leaves. When it is necessary to hold cauliflower temporarily out of cold storage, packing in crushed ice will aid in keeping it fresh. Freezing causes a grayish brown discoloration, softening of the curd, and a watersoaked condition. Affected tissues are rapidly invaded by soft rot bacteria.

Much of the cauliflower now marketed has closely trimmed leaves and is prepackaged in perforated cellophane overwraps that are then packed in fiberboard containers. Vacuum cooling is a fairly efficient method of cooling prepackaged cauliflower. In general, use of controlled atmospheres with cauliflower has not been promising. Atmospheres containing 5% CO₂ or higher are injurious to cauliflower, although the damage may not be apparent until after cooking.

Bacterial Soft Rot. See [Table 5](#), Note 1.

Brown Rot (*Alternaria*). Brown or black spotting of the curd. *Control:* Use seed treatment and field spraying. Keep the curds dry. Maintain low transit temperatures. Store at 0°C.

Celery (0°C and 98 to 100% rh)

Celery is a relatively perishable commodity, and for storage of 1 to 2 months, it is essential that a commodity temperature of 0°C be maintained. The rh should be high enough to prevent wilting (98 to 100%). Considerable heat is given off because of respiration, and for this reason the stacks of crates should be separated and dunnage used to allow cold air circulation under and over the crates and between the bottom crates and the floor. Forced-air circulation should be provided; otherwise there may be a 1 to 2 K temperature differential between the top and the bottom of the room.

Celery can be cooled by forced-air cooling, hydrocooling, or vacuum cooling. Hydrocooling is the most common cooling method; temperatures should be brought to as near 0°C as possible. In practice, temperatures are reduced to 4 to 7°C. Vacuum cooling is widely used for celery packed in corrugated cartons for long-distance shipment.

Bacterial Soft Rot. See [Table 5](#), Note 1.

Black Heart. Brown or black discoloration of tips or all of the heart leaves. Affected celery should not be stored because of rapid development of bacterial soft rot. *Control:* Good cultural practices with special attention to available calcium. Harvest promptly after celery is mature.

Early Blight (*Cercospora*). Circular pale yellow spots on leaflets. In advanced stages, spots coalesce and become brown to ashen gray. No spots develop in storage, but affected lots lose moisture and their fresh appearance. *Control:* Control early blight in the field by spraying or dusting.

Freezing Injury. Characteristic loosening of the epidermis is best demonstrated by twisting the leaf stem. Severe freezing causes celery to become limp and to dry out rapidly. Freezing may cause watery soft rot and bacterial soft rot. The freezing point is about -0.5°C.

Late Blight (*Septoria*). Small (3 mm or less), yellowish, indefinite spots in the leaflet and elongated spots on the leaf stalk bearing black fruiting bodies of pinpoint size on the surface and surrounding green tissue. Development of blight in storage is probably negligible, but it opens the way for storage decays. *Control:* Control late blight in the field with sanitary measures and fungicides. Store infected lots for short periods only.

Mosaic. Leaflets are mottled; the stalk shows brownish sunken streaks. Badly affected stalks shrivel. *Control:* Eradicate weeds that carry the virus. Grade out all discolored stalks at packing time.

Watery Soft Rot (Pink Rot). This is the principal decay of celery. It is often severe on field-frozen stock and on celery harvested

after prolonged cool, moist weather. In early stages, it often has a pink color. *Control:* Grade out all discolored stalks at packing time. Storage at 0°C will retard but not prevent the disease.

Corn, Sweet (0°C and 95 to 98% rh)

Sweet corn is highly perishable and is seldom stored except to temporarily protect an excess supply. Corn, as it usually arrives on the market, should not be expected to keep for more than 4 to 8 days even in 0°C storage.

The sugar content, which so largely determines quality in corn and decreases rapidly at ordinary temperatures, decreases less rapidly if the corn is kept at about 0°C. The loss of sugar is about 4 times as rapid at 10°C as it is at 0°C.

Sweet corn should be cooled promptly after harvest. Usually, corn is hydrocooled, but vacuum cooling is also satisfactory if the corn is prewetted and top-iced after cooling. Where precooling facilities are not available, corn can be cooled with package and top ice. Sweet corn should not be handled in bulk unless it is copiously iced because of its tendency to heat throughout the pile. Sweet corn ears should be trimmed to remove most shank material before shipment to minimize moisture loss and prevent kernel denting. A loss of 2% moisture from sweet corn can result in objectionable kernel denting.

Cucumbers (10 to 13°C and 95% rh)

Cucumbers can be held only for short periods of 10 to 14 days at 10 to 13°C with a relative humidity of 95%. Cucumbers held at 7°C or below for longer periods develop surface pitting or dark-colored watery areas. These blemishes indicate chilling injury. Such areas soon become infected and decay rapidly when the cucumbers are moved to warmer temperatures. Slight chilling may develop in 2 days at 0°C and severe chilling injury within 6 days at 0°C. The susceptibility of cucumbers to chilling injury does not preclude their exposure to temperatures below 10°C for short intervals as long as they are used immediately after removal from cold storage. Chilling symptoms develop rapidly only at higher temperatures. Thus, 2 days at 0°C or 4 days at 4°C are both harmless. Waxing is of some value in reducing loss of mass and in giving a brighter appearance. Shrink wrapping with polyethylene film can also prevent the loss of turgidity.

At temperatures of 10°C and above, cucumbers ripen rather rapidly as the green color changes to yellow. Ripening is accelerated if they are stored in the same room with ethylene-producing crops for more than a few hours.

Anthracnose (*Colletotrichum*). Circular, sunken, watersoaked spots that soon produce pink spore masses in the center. Later, the spots turn black. *Control:* Use disease-free seed and fungicidal applications in the field.

Bacterial Soft Rot. See [Table 5](#), Note 1.

Bacterial Spot (*Pseudomonas*). Small, circular, watersoaked spots, later chalky or moist with gummy exudate. *Control:* If possible, avoid shipping infected cucumbers. Pack them dry and maintain temperatures as near optimum as practicable.

Black Rot (*Mycosphaerella*). Irregular, brownish, watersoaked spots of varying size, later nearly black. Black fruiting bodies are sometimes present. *Control:* Exclude infected cucumbers from the pack, if possible. Reduce carrying temperatures to about 10°C.

Chilling Injury. Numerous sunken and slightly watersoaked areas in the skin of cucumbers after removal from storage, found on cucumbers stored for longer than a week at temperatures below 7°C. *Control:* Store cucumbers at temperatures between 10 and 13°C, for no longer than 2 weeks.

Cottony Leak (*Pythium*). Large, greenish, watersoaked lesions. Luxuriant, white, cottony mold over wet decay. *Control:* Exclude infected cucumbers from the pack, if possible. Reduce carrying temperatures to about 10°C.

Freezing Injury. Large areas in cucumbers that are soft, flabby, watersoaked, and wrinkled, especially toward the stem end. *Control:* Prevent exposure to temperatures below -0.5°C .

Watery Soft Rot. See [Table 5](#), Note 4.

Eggplants (8 to 12°C and 90 to 95% rh)

Eggplants are not adapted to long storage. They cannot be kept satisfactorily even at the optimum temperatures of 8 to 12°C for over a week and still retain good condition during retailing. Eggplants are subject to chilling injury at temperatures below 7°C . Surface scald or bronzing and pitting after sand scarring are symptoms of chilling injury. Eggplants that have been chilled are subject to decay by *Alternaria* when they are removed from storage. Exposure to ethylene for 2 or more days hastens deterioration.

Cottony Leak (*Pythium*). Decayed areas are large, bleached, discolored (tan), wrinkled, moist, and soft; later they exhibit abundant cottony mold. *Control:* Reduce carrying temperatures to about 8°C .

Fruit Rot (*Phomopsis*). Numerous, somewhat circular brown spots that later coalesce over much of the fruit with pycnidia dotting the older lesions. This is a very common decay of eggplant. *Control:* Use fungicide sprays in the field. Reduce carrying temperature to about 8°C . Move the fruit promptly if decay is evident.

Endive and Escarole (0°C and 95 to 100% rh)

Endive and escarole are leafy vegetables not adapted to long storage. Even at 0°C , which is considered the best storage temperature, they will not keep satisfactorily for more than 2 or 3 weeks. They should keep somewhat longer if they are stored with cracked ice in or around the packages. Some desirable blanching usually occurs in endive held in storage.

Garlic, Dry (0°C and 65 to 70% rh)

If it is in good condition and is well cured when stored, garlic should keep at 0°C for 6 to 7 months. Garlic cloves sprout most rapidly at 4 to 18°C ; therefore, prolonged storage at this temperature should be avoided. In California, it is frequently put in common storage, where it can be held 3 to 4 months or sometimes longer if the building can be kept cool, dry, and well ventilated.

Blue Mold Rot (*Penicillium*). Soft, spongy, or powdery dry decay of cloves. Affected cloves finally break down completely into gray or tan powdery masses. *Control:* Prevent bruising; keep garlic dry.

Waxy Breakdown. Yellow or amber waxy translucent breakdown of the outside cloves. *Control:* No control measures have been developed.

Greens, Leafy (0°C and 95 to 100% rh)

Leafy greens such as collards, chard, and beet and turnip greens are very perishable and should be held as close to 0°C as possible. At this temperature, they can be held 10 to 14 days. They are commonly shipped with package and top ice to maintain freshness and are handled like spinach. Kale packed with polyethylene crate liners should keep at least 3 weeks at 0°C or 1 week at 4°C . Vitamin content and quality are retained better when wilting is prevented.

Lettuce (0°C and 95 to 100% rh)

Lettuce is highly perishable. To minimize deterioration, it requires a temperature as close to its freezing point as possible without actually freezing it. Lettuce will keep about twice as long at 0°C as at 3°C . If it is in good condition when stored, lettuce should keep 2 to 3 weeks at 0°C with a high relative humidity. Most lettuce is packed in cartons and vacuum-cooled to about 1 to 2°C soon after harvest. It should then be immediately loaded into refrigerated cars or trailers for shipment or placed in cold storage rooms for holding prior to shipping.

An increasing quantity of lettuce is shipped in modified atmospheres to aid quality retention. Modified atmospheres are a supple-

ment to proper transit refrigeration but are not a substitute for refrigeration. Head lettuce is not tolerant of CO_2 and is injured by concentrations of 2 to 3% or higher. Romaine is injured by 10% CO_2 , but not by 5% at 0°C . Leaf lettuce and chopped romaine tolerate 10% CO_2 , and chopped, shredded iceberg lettuce tolerates 15% CO_2 (Gorny 1997).

Excess wrapper leaves are usually trimmed off before sale or use, so it is suggested that lettuce be trimmed to two wrapper leaves before packaging (rather than the usual five or six) to save space and mass. The extra wrapper leaves are not needed to maintain quality.

Bacterial Soft Rot. The most common cause of spoilage in transit and storage. Often, it starts on bruised leaves. This decay normally is the controlling factor in determining the storage life of lettuce and is much less serious at 0°C than at higher temperatures (see [Table 5](#), Note 1).

Brown Stain. Lesions that are typically tan, brown, or even black and about 6 mm wide and 12 mm long with distinct margins that are darker than the slightly sunken centers. The margins give a halo effect. The lesions develop on head leaves just under the cap leaves. The heart and wrapper leaves are not affected. Brown stain is caused by CO_2 accumulation from normal product respiration in railcars or trailers. *Control:* Ventilate to keep CO_2 below 2% in transport vehicles by keeping one water drain open. Enclose bags of hydrated lime (in vehicles shipped under a modified atmosphere) to absorb CO_2 .

Gray Mold. See [Table 5](#), Note 2.

Pink Rib. Characterized by diffuse pink discoloration near the bases of the midribs of the outer head leaves. In heads with severe symptoms, all but the youngest head leaves may be pink and discoloration may reach into large veins. The cause has not been identified but shipment in low O_2 atmospheres at undesirably high temperatures (10°C) can accentuate the disease. It is most common in hard to overmature lettuce. *Control:* Store and ship lettuce at recommended low temperatures.

Russett Spotting. This occasionally causes serious losses. Small tan or rust-colored pitlike spots appear mostly on the midrib but possibly develop on other parts of leaves. Exposure to ethylene and to storage or transport temperatures above 3°C are the main causes of this disorder. Hard lettuce is more susceptible to it than firm lettuce. *Control:* Avoid storing or shipping lettuce with apples, pears, or other products that give off ethylene. Precool lettuce adequately to 1 to 3°C and refrigerate it continuously. Shipment in a low O_2 atmosphere (1 to 8%) allows effective control.

Rusty Brown Discoloration. A serious market disorder of western head lettuce; a diffuse discoloration which tends to follow the veins but also spreads to adjacent tissue. The disorder starts on the outer head leaves but in severe cases may affect all leaves. *Control:* There is no known control method.

Tipburn. Dead brown areas along the edges and tips of inner leaves. This is considered to be of field origin, but occasionally the severity of the disease increases after harvest. *Control:* Keep the affected stock well cooled and market it promptly after unloading to avoid secondary bacterial rots.

Watery Soft Rot. See [Table 5](#), Note 4.

Melons

Persians should keep at 7 to 10°C for up to 2 weeks; **honeydews** for 2 to 3 weeks; and **casabas** for 4 to 6 weeks. These melons will definitely be injured in 8 days at temperatures as low as 0°C . Honeydews are usually given an 18 to 24 h ethylene treatment (5000 mg/kg) to obtain uniform ripening. Pulp temperature should be 21°C or above during treatment. Honeydews must be mature when harvested; immature melons fail to ripen even if treated with ethylene.

Cantaloupes harvested at the hard-ripe stage (less than full slip) can be held about 15 days at 2 to 3°C . Lower temperatures may cause chilling injury. Full-slip hard-ripe cantaloupes can be held for

a maximum of 10 to 14 days at 0 to 2°C. They are more resistant to chilling injury. Cantaloupes are precooled by hydrocooling or forced-air cooling before loading or by top-icing after loading in railcars or trucks.

Watermelons are best stored at 10 to 15°C and should keep for 2 to 3 weeks. Watermelons decay less at 0°C than at 4°C, but they tend to become pitted and have an objectionable flavor after 1 week at 0°C. At low temperatures, they are subject to various symptoms of chilling injury (loss of flavor and fading of red color). Watermelons should be consumed within 2 to 3 weeks after harvest, primarily because of the gradual loss of crispness.

Alternaria Rot. Irregular, circular, brownish spots, sometimes with concentric rings, later covered with black mold. Often found on melons that have been chilled. *Control:* Avoid chilling temperatures. If cold melons are to be held at room temperature, they should be so stacked that condensed moisture will evaporate readily. Market melons promptly.

Anthraxnose (Colletotrichum). Numerous greenish, elevated spots with yellow centers, later sunken and covered with moist pink spore masses. *Control:* Apply recommended field control measures.

Chilling Injury. Honeydew and honeyball melons stored for 2 weeks or longer at temperatures of 0 to 1°C sometimes show large, irregular, water soaked, sticky areas in the rind. *Control:* Store melons at 7 to 10°C.

Cladosporium Rot. Small black shallow spots later covered with velvety green mold. On cantaloupes, this rot is evident on extensive shallow areas at the stem ends or at points of contact between melons and it can be rubbed off easily. *Control:* Control measures are the same as for *Alternaria* rot.

Fusarium Rot. Brown areas on white melons; white or pink mold over indefinite spots on green melons. Affected tissue is spongy and soft with white or pink mold. *Control:* Avoid mechanical injuries; reduce carrying temperatures to 7°C.

Phytophthora Rot. Brown slightly sunken areas; later water-soaked and covered with a wet, appressed, whitish mold. *Control:* Cull out the affected fruits during packing. Reduce carrying temperatures to 7°C.

Rhizopus Rot. The affected melon is soft but not soupy and leaky as it is in similar decay on other vegetables. Coarse fungus strands may be demonstrated in decayed tissue (See [Table 5](#), Note 3).

Stem End Rot (Diplodia). Fairly firm brown decay usually starting at the stem end and affecting a large part of the watermelon. Black fruiting bodies develop later. *Control:* At the time of loading in cars, recut the stems and treat them with Bordeaux paste or another recommended fungicide.

Mushrooms (0°C and 95% rh)

Mushrooms are usually sold in a retail market within 24 to 48 h after harvesting. They keep in good salable condition at 0°C for 5 days, at 4°C for 2 days, and at 10°C or above for about 1 day. A rh of 95% is recommended during storage. While being transported or displayed for retail sale, mushrooms should be refrigerated. Deterioration is marked by brown discoloration of the surfaces, elongation of the stalks, and opening of the veils. Black stems and open veils are correlated with dehydration.

Controlled atmosphere storage can prolong the shelf life of mushrooms held at 10°C, if the O₂ concentration in the atmosphere is 9% or the CO₂ concentration is 25 to 50%.

Moisture-retentive film overwraps of caps usually help in reducing moisture loss.

Okra (7 to 10°C and 90 to 95% rh)

Okra deteriorates rapidly and is normally stored only briefly before marketing or processing. It has a very high respiration rate at

warm temperatures. Okra in good condition can be kept satisfactorily for 7 to 10 days at 7 to 10°C. A relative humidity of 90 to 95% is desirable to prevent wilting. At temperatures below 7°C, okra is subject to chilling injury which is shown by surface discoloration, pitting, and decay. Holding okra for 3 days at 0°C may cause pitting. Contact or top ice causes water spotting in 2 or 3 days at all temperatures.

Fresh okra bruises easily; the damaged areas blacken within a few hours. A bleaching injury may also develop when okra is held in hampers for more than 24 h without refrigeration.

Onions (0°C and 65 to 70% rh)

A comparatively low relative humidity is essential in the successful storage of dry onions. However, humidities as high as 85% and forced-air circulation also have given satisfactory results. At higher humidities, at which most other vegetables keep best, onions develop root growth and decay; at too high a temperature, sprouting occurs. Storage at 0°C with 65 to 70% rh is recommended to keep them dormant.

Onions should be adequately cured in the field, in open sheds, or by artificial means before, or in, storage. The most common method of curing in northern areas is by forced ventilation in storage. Onions are considered cured when the necks are tight and the outer scales are dried until they rustle. If they are not cured, onions are likely to decay in storage.

Onions are stored in 23-kg bags, in crates, in pallet boxes that hold about 450 kg of loose onions, or in bulk bins. Bags of onions are frequently stored on pallets. Bagged onions should be stacked to allow proper air circulation.

In the northern onion-growing states, onions of the globe type are generally held in common storage because average winter temperatures are sufficiently low. They should not be held after early March unless they have been treated with maleic hydrazide in the field to reduce sprout growth.

Refrigerated storage is often used to hold onions for marketing in late spring. Onions to be held in cold storage should be placed there immediately after curing. A temperature of 0°C will keep onions dormant and reasonably free from decay, provided the onions are sound and well cured when stored. Sprout growth indicates too high a storage temperature, poorly cured bulbs, or immature bulbs. Root growth indicates the relative humidity is too high.

Globe onions can be held for 6 to 8 months at 0°C. Mild or Bermuda types can usually be held at 0°C for only 1 to 2 months. Spanish onions are often stored; if well matured, they can be held at 0°C at least until January or February. In California, onions of the sweet Spanish type are held at 0°C until April or May.

Onions are damaged by freezing, which appears as watersoaking of the scales when cut after thawing. If allowed to thaw slowly and without handling, onions that have been slightly frozen may recover with little perceptible injury. When onions are removed from storage in warm weather, they may sweat due to condensation of moisture. This may favor decay. Warming onions gradually (for example to 10°C over 2 to 3 days) with good air movement should avoid the difficulty. Onions should not be stored with other products that tend to absorb odors.

Onion sets require practically the same temperature and humidity conditions as onions, but because they are smaller in size they tend to pack more solidly. They are handled in approximately 11-kg bags and should be stacked to allow the maximum air circulation.

Green onions (scallions) and green shallots are usually marketed promptly after harvest. They can be stored 3 to 4 weeks at 0°C with 95% rh. Crushed ice spread over the onions aids in supplying moisture. Packaging in polyethylene film also aids in preventing moisture loss. Storage life of green onions at 0°C can be extended to 8 weeks by (1) packaging them in perforated polyethylene bags or in waxed cartons and (2) holding them in a controlled atmosphere of 1% O₂ with 5% CO₂.

Ammonia Gas Discoloration. Exposure of onions to 1% ammonia in air for 24 h causes the surface of yellow onions to turn brown, red onions to turn deep metallic black, and white onions to turn greenish yellow. *Control:* Ventilate storage rooms as soon as possible after exposure.

Bacterial Soft Rot. This decay often affects one or more scales in the interior of the bulb. Decayed tissue is more mushy than gray mold rot (See [Table 5](#), Note 1).

Black Mold (*Aspergillus*). Black powdery spore masses on the outermost scale or between outer scales. *Control:* Store onions at just above 0°C and at 65% rh.

Freezing Injury. A watersoaked, grayish yellow appearance of all the outer fleshy scales results from a slight freezing injury. All scales are affected and become flabby with severe injury. Opaque areas appear in affected scales. *Control:* Prevent exposure to -1°C temperatures and lower. Thaw frozen onions at 4°C.

Fusarium Bulb Rot. Semiwatery to dry decay progressing up the scales from the base. Decay is usually covered with dense, low-lying white to pinkish mold. *Control:* Do not store badly affected lots. Pull out infected bulbs in slightly affected lots. Store onions at 0°C.

Gray Mold Rot (*Botrytis*). This is the most common type of onion decay; it usually starts at the neck, affecting all scales equally. Decay often is pinkish (See [Table 5](#), Note 2). *Control:* Cure onions thoroughly. Protect them from rain. Store them at just above 0°C.

Smudge. Black blotches or aggregations of minute black or dark green dots on the outer drying scales of white onions. Under moist conditions sunken yellow spots develop on fleshy scales. *Control:* Protect onions from rain after harvest. Store them just above 0°C.

Translucent Scale. The outer 2 or 3 scales are gray and watersoaked, as in freezing. The entire scale may not be discolored; no opaque area is noticeable. Sometimes translucent scale is found in the field. *Control:* No control is known. Store onions at 0°C after curing.

Parsley (0°C and 95 to 100% rh)

Parsley should keep 1 to 2.5 months at 0°C and for a somewhat shorter period at 2 to 3°C. High humidity is essential to prevent desiccation. Package icing is often beneficial.

Bacterial Soft Rot. See [Table 5](#), Note 1.

Watery Soft Rot. See [Table 5](#), Note 4.

Parsnips (0°C and 98 to 100% rh)

Topped parsnips have similar storage requirements to topped carrots and should keep for 2 to 6 months at 0°C. Parsnips held at 0 to 1°C for 2 weeks after harvest attain a sweetness and high quality equal to that of roots subjected to frosts for 2 months in the field. Ventilated polyethylene box or basket liners can aid in preventing moisture loss. Parsnips are not injured by slight freezing while in storage, but they should be protected from hard freezing. They should be handled with great care while frozen. The main storage problems with parsnips are decay, surface browning, and their tendency to shrivel. Refrigeration and high relative humidity will retard deterioration.

Bacterial Soft Rot. See [Table 5](#), Note 1.

Canker (*Iterosonilia* sp.). An organism enters through fine root-lets and through injuries. The surface of the infected parsnip is first brown to reddish; later, it turns black where a depressed canker is formed. *Control:* Follow the recommended field spray program. Practice crop rotation.

Gray Mold Rot (*Botrytis*). See [Table 5](#), Note 2.

Watery Soft Rot. See [Table 5](#), Note 4.

Peas, Green (0°C and 95 to 98% rh)

Green peas lose part of their sugar rapidly if they are not refrigerated promptly after harvest. They should keep in salable condition for 1 to 2 weeks at 0°C. Top icing is beneficial in maintaining freshness. Peas keep better unshelled than shelled.

Bacterial Soft Rot. See [Table 5](#), Note 1.

Gray Mold Rot (*Botrytis*). See [Table 5](#), Note 2.

Watery Soft Rot. See [Table 5](#), Note 4.

Peas, Southern (4 to 5°C and 95% rh)

Freshly harvested southern peas at the mature-green stage should have a storage life of 6 to 8 days at 4 to 5°C with high relative humidity. Without refrigeration, they remain edible for only about 2 days, the pods yellowing in 3 days and showing extensive decay in 4 to 6 days.

Peppers, Dry Chili or Hot

Chili peppers, after drying to a moisture content of 10 to 15%, are stored in nonrefrigerated warehouses for 6 to 9 months. The moisture content is usually low enough to prevent fungus growth. A relative humidity of 60 to 70% is desirable. Polyethylene-lined bags are recommended to prevent changes in moisture content. Manufacturers of chili pepper products hold part of their raw material supply in cold storage at 0 to 10°C, but they prefer to grind the peppers as soon as possible and to store them in the manufactured form in airtight containers.

Peppers, Sweet (7 to 13°C and 90 to 95% rh)

Sweet peppers can be stored for a maximum of 2 to 3 weeks at 7 to 13°C. They are subjected to chilling injury if they are stored at temperatures below 7°C. The symptoms of this injury are surface pitting and discoloration near the calyx, which develops a few hours after removal from storage. At temperatures of 0 to 2°C peppers usually develop pitting in a few days. When stored at temperatures above 13°C, ripening (red color) and decay develop rapidly. Rapid cooling of harvested sweet peppers is essential in reducing marketing losses. It can be done by forced-air cooling, hydrocooling, or vacuum cooling. Forced air cooling is the preferred method. Peppers are often waxed commercially, which reduces in-transit chafing and moisture loss.

Bacterial Soft Rot. See [Table 5](#), Note 1.

Freezing Injury. The outer wall is soft, flabby, watersoaked, and dark green in color. The core and seeds turn brown with severe freezing. Sweet peppers freeze at about -0.5°C.

Gray Mold Rot (*Botrytis*). See [Table 5](#), Note 2.

Rhizopus Rot. See [Table 5](#), Note 3.

Potatoes (Temperature, see following; 90 to 95% rh)

The proper potato storage environment will promote the most rapid healing of bruises and cuts, reduce rot penetration to a minimum, allow the least loss of mass and other storage losses to occur, and reduce to a minimum the deleterious quality changes that might occur during storage.

Early-crop potatoes are usually stored only during congested periods. They are more perishable and do not keep as well or as long as late-crop tubers. Refrigerated storage at 4°C, following a curing period of 4 or 5 days at 21°C, is recommended; they also can be stored for about 2 months at 10°C without curing. If early-crop potatoes are to be used for chipping or French frying, storage at 21°C is recommended. Holding these potatoes in cold storage (even at moderate temperatures of 10 to 13°C) for only a few days causes excessive accumulation of reducing sugars, which results in production of dark-colored chips.

Late-crop potatoes produced in the northern half of the United States are usually stored. The greater part of the crop is held in nonrefrigerated commercial and farm storages, but some potatoes are held in refrigerated storages. Potatoes in nonrefrigerated storages are usually held in bulk bins 2.4 to 6.1 m deep. Shallower bins are used in milder climates. Some potatoes are stored in pallet boxes. In refrigerated warehouses, potatoes can be stored in sacks, pallet boxes, or bulk.

Late-crop potatoes should be cured immediately after harvest by being held at 10 to 16°C and high relative humidity for about 10 to 14 days to permit suberization and wound periderm formation (healing of cuts and bruises). If properly cured, they should keep in sound dormant condition at 3 to 4°C with 95% rh for 5 to 8 months. A lower temperature is not desirable, except in the case of seed stock for late planting. For this purpose, 3°C is best. At 3°C or below, Irish potatoes tend to become sweet. For ordinary table use, potatoes stored at 4°C are satisfactory, but they will probably be unsatisfactory for chipping or French frying unless desugared or conditioned at about 18 to 21°C for 1 to 3 weeks before use. However, conditioning may be costly and good results are often uncertain.

Potatoes will remain dormant at 10°C for 2 to 4 months; since tubers from this temperature are more desirable for both table use and processing than those from 4°C, late-crop potatoes intended for use within 4 months should be stored at 10°C and those for later use at 4°C. All potatoes should be stored in the dark to prevent greening.

A storage temperature of 10 to 13°C is recommended for most cultivars of potatoes intended for chip manufacture. At these temperatures, they usually remain in satisfactory condition if their reducing-sugar content is low enough when they are initially stored. Storage at 16 to 18°C is less desirable because shrinkage, internal and external sprout growth, and decay are greater at these temperatures than at 10 to 13°C. Russet Burbank potatoes for table stock or for chipping are stored at 7°C with 95% rh.

Potatoes usually do not sprout until 2 to 3 months after harvest, even at 10 to 16°C. However, after 2 to 3 months of storage, sprouting occurs in potatoes stored at temperatures above 4°C and particularly at temperatures around 16°C. Although limited sprouting does not affect potatoes for food purposes, badly sprouted stock shrivels and is difficult to handle and market.

Certain growth-regulating chemicals have been approved by the U.S. Food and Drug Administration to control or reduce sprouting on potatoes. Potatoes treated with chemical sprout inhibitors should not be stored in the same warehouse with seed potatoes. If 90% rh or slightly higher is maintained, potatoes will have the best quality and the least amount of shrinkage. Cunningham et al. (1971) recommend 95% rh or higher for late-crop potatoes. Condensation on the ceiling and resultant moisture drip is sometimes a problem when very high humidity is maintained.

Ventilation or air circulation in potato storage is needed to provide and maintain optimum temperature and relative humidity throughout storage and the tubers it contains. In northern states, where average outdoor temperatures during storage are low, little circulation or ventilation is needed. Shell or perimeter circulation is extensively used in these areas for seed and table stock potatoes. Forced circulation through the potatoes is required for the higher-temperature storage of processing potatoes and for table and seed stock in the warmer parts of the late-crop area. Rapid air circulation may lower the relative humidity of the air immediately surrounding the potatoes; it is conducive to drying and loss of mass, which may be desirable if there are disease problems but undesirable with sound potatoes because of increased shrinkage. For late-crop Idaho potatoes, a uniform airflow, which does not have to be continuous, of 0.0068 L/(s·kg) is recommended. With this ventilation, Russet Burbank potatoes stored at 7°C with 95% rh should keep in good condition for 10 months or longer.

Potatoes can absorb objectionable flavors or odors from fruit, nuts, eggs, dairy products, and volatile chemicals; consequently they should not be kept in the same room.

Bacterial Ring Rot. Yellow, soft, cheesy decay of the thin layer of tissue in the vascular ring. The outer 6 mm of the tuber and the inner part may appear normal. *Control:* Use disease-free seed; store promptly at 4°C.

Bacterial Soft Rot. See [Table 5](#), Note 1. This disease probably causes more loss in the early and intermediate crops than all other potato diseases combined.

Freezing Injury. If frozen solidly, tubers become soft and cream-colored and exude moisture. Slightly frozen tubers show darkening of the vascular ring and dull gray to black areas in the flesh. Potatoes freeze at about -1°C.

Fusarium Rot. Brown to black, spongy, and fairly dry; white or pink mold inside cavities of stored potatoes. *Control:* Avoid cutting and bruising during harvesting. After proper curing, maintain well-ventilated storage at 4°C.

Late Blight (*Phytophthora*). Reddish brown to black granular discoloration of the outer 3 to 6 mm of tuber. The affected tissue is firm to rock hard. *Control:* Apply recommended fungicides in the field. Kill vines prior to harvesting tubers or keep tubers away from blighted vines at harvest. Keep them dry; store at 4°C; market promptly.

Leak (*Pythium*). A large, gray to black, moist, decayed area starting at bruises or the stem end of the tuber. The internal tissue is granular and cream-colored at first, turning through reddish brown to inky black. *Control:* Prevent bruising. Refrigerate tubers to 4°C and keep them dry.

Mahogany Browning. Reddish brown patches or blotches in the flesh of tubers. Chippewa and Katahdin varieties are most susceptible. This differs from flesh discoloration caused by freezing in being reddish brown instead of gray. *Control:* Store at 4°C or above because lower temperatures cause the discoloration.

Net Necrosis. Dark brown vascular ring and vascular netting of the flesh, most prominent at the stem end, but extends well toward the bud end; increases during storage. *Control:* Reduce storage temperature promptly to 4°C; the infected tubers show symptoms earlier at higher temperatures.

Scald and Surface Discoloration. On early potatoes, this appears as sunken injured areas; later, it turns black and sticky and is followed by bacterial rots. *Control:* Move potatoes promptly to market; cool to 4°C.

Southern Bacterial Wilt. Moist, sticky exudation from the vascular ring when the tuber is cut. Sometimes there is advanced mushy decay in the center of the tuber. *Control:* Avoid shipping infected tubers; market promptly.

Stem End Browning. Dark brown to black vascular tissue, occurs in streaks that extend 10 to 25 mm into the flesh from the stem end; develops during storage. *Control:* After curing, reduce the storage temperature promptly to 4°C. Higher temperatures allow rapid development in susceptible lots.

Tuber Rot (*Alternaria*). Black to purplish, slightly sunken, shallow, irregularly shaped lesions, 6 to 25 mm in diameter, developing during storage. *Control:* Apply recommended fungicides in the field. Keep the tubers away from blighted vines as much as possible at harvest. If the tubers are damp, inspect them frequently during storage and use forced-air ventilation to dry up excess moisture.

Pumpkins and Squash

Hard-shell winter squash, such as the Hubbards, can be successfully stored for 6 months or longer at 10 to 13°C with a relative humidity of 60 to 75%. Dry storage is needed for quality retention. All specimens should be well-matured, carefully handled, and free from injury or decay when stored. Hubbard and other dark-green-skinned squashes should not be stored near apples, as the ethylene from apples may cause the squashes' skin to turn orange-yellow. Most varieties of **pumpkins** do not keep in storage for as long as the usual storage varieties of squash. Such varieties as Connecticut Field and Cushaw do not keep well and cannot be kept in good condition for more than 2 to 3 months. **Acorn squash** can be stored satisfactorily for 5 to 8 weeks at 10°C. **Butternut squash** should keep at least 2 to 3 months at 10°C with 50% rh.

Summer squash, such as yellow crookneck and giant straight-neck, are harvested at an immature stage for best quality. The skin is tender and these varieties are easily wounded and perishable. The storage temperature range for summer squash is 5 to 10°C with 95%

rh. A temperature of 5°C is best for zucchini squash stored up to 2 weeks, since they are sensitive to chilling injury.

Black Rot (*Mycosphaerella*). Hard, dry, black decay, dotted with minute black pimplelike fruiting bodies that occurs at stem ends or sides of the fruit. *Control:* Avoid skin breaks on the fruit; handle promptly.

Dry Rots (*Alternaria*; *Cladosporium*; *Fusarium*). Small, deep, dry, decayed areas. The decayed portion is easily lifted out of the surrounding healthy tissue. The surface mold is low-growing and either greenish black or pinkish white in color. *Control:* Prevent skin breaks. Do not store hard shell squashes below 10°C.

Rhizopus Rot. See [Table 5](#), Note 3.

Radishes (0°C and 95 to 100% rh)

After harvest, topped spring radishes should be precooled quickly, often by hydrocooling, to 5°C or below. If they are then packaged in polyethylene bags, radishes can usually be held 3 to 4 weeks at 0°C and for a somewhat shorter time at 4°C.

Bunched radishes with tops are more perishable. They can be stored at 0°C and 95 to 100% rh for 1 to 2 weeks.

Rhubarb (0°C and 95% rh)

Fresh rhubarb stalks wilt and decay rapidly. Rhubarb in good condition can be stored 2 to 4 weeks at 0°C with a 95% rh or above. Moisture loss during holding or storage can be minimized by using nonsealed polyethylene crate liners or by film wrapping consumer size bunches. Removing and discarding leaf blades at harvest is desirable, because it not only reduces the possibility of decay and loss of mass but also reduces shipping mass and package size by one-third. Rhubarb is usually marketed with about 10 mm of the leaf blade attached to the petiole. Splitting of the petiole is more serious if the entire leaf is removed.

Fresh rhubarb cut into 25-mm pieces and packaged in 0.5-kg perforated polyethylene bags can be held 2 to 3 weeks at 0°C with high relative humidity. Splitting of cut ends and curling of these pieces in film bags may be a problem if marketing is at warm temperatures.

Gray Mold Rot (*Botrytis*). Grayish, smoke-colored growths and grayish brown spore masses on stalks. *Control:* Refrigerate to 0°C.

Phytophthora Rots (*Phytophthora*). Watery, greenish brown, sunken lesions starting at the base of the leafstalk and causing brown decay. *Control:* Decay is retarded with transit and storage temperatures below 4°C.

Rutabagas (0°C and 98 to 100% rh)

Rutabagas lose moisture and shrivel readily if they are not stored under high humidity conditions. A hot paraffin wax coating, often given to rutabagas, is effective in preventing wilting and loss of mass; it also slightly improves appearance. Too heavy a wax coating may produce severe injury from internal breakdown caused by sub-oxidation. Rutabagas in good condition, when stored, should keep 4 to 6 months at 0°C.

Freezing Injury. Rare, because the commodity can stand slight freezing without injury. Severe freezing causes watersoaking and light browning of the flesh, a mustard odor, and fermentation. *Control:* Prevent repeated slight freezing or severe freezing.

Gray Mold Rot (*Botrytis*). See [Table 5](#), Note 2.

Spinach (0°C and 95 to 98% rh)

Spinach is very perishable and can be stored for only short periods of 10 to 14 days at 0°C with 95 to 98% rh. It will deteriorate rapidly at higher temperatures. Spinach is commercially vacuum cooled and forced-air cooled. If it is thoroughly cooled, it can be held for 10 to 14 days at 0°C without the addition of any package ice prior to storage. When precooling facilities are not available, crushed ice should be placed in each package to provide rapid cooling and to take care of the heat of respiration. Top ice is also beneficial.

Bacterial Soft Rot. See [Table 5](#), Note 1.

Downy Mildew (*Peronospora*). A field disease, commonly found at the marketing stage as pale yellow irregular areas in the leaves. Downy gray mold is present on the lower surface. *Control:* Control it in the field; market promptly.

White Rust (*Albugo*). Slight yellowing of areas in the leaf above white blisterlike pustules filled with white masses of spores. *Control:* Control it in the field.

Sweet Potatoes (13 to 16°C, 85 to 90% rh)

Most sweet potatoes are stored in nonrefrigerated commercial or farm storages. Preliminary curing at 29°C and 90 to 95% rh for 4 to 7 days is essential in the healing of injuries received in harvesting and handling and in preventing the entrance of decay organisms. After curing, the temperature should be reduced to 13 to 16°C, usually by ventilating the storage, and the relative humidity should be retained at 85 to 90%. Most varieties will keep satisfactorily for 4 to 7 months under these conditions. Loss of mass of 2 to 6% can be expected during curing and about 2% a month during subsequent storage.

Usually, sweet potatoes will not keep satisfactorily if they have been subjected to excessively wet soil conditions just before harvest or chilled before or after harvest by exposure to temperatures of 10°C or below. Short periods at temperatures as low as 10°C need not cause alarm; but after a few days at lower temperatures, sweet potatoes may develop discoloration of the flesh, internal breakdown, increased susceptibility to decay, and off-flavors when cooked.

Temperatures above 16°C stimulate development of sprouting (especially at high humidities), pithiness, and internal cork (a virus disease). Refrigeration is frequently used in large sweet potato storages to extend the marketing season into warm weather when ventilation will not maintain low enough temperatures.

Sweet potatoes are usually stored in slatted crates or bushel baskets. Palletization of crates and use of pallet boxes facilitates handling. Sweet potatoes are usually washed and graded and are sometimes waxed before being shipped to market. They may be treated with a fungicide to reduce decay during marketing.

Black Rot (*Ceratocystis*). Greenish black decay, frequently fairly shallow, and sometimes circular in outline at the surface. *Control:* Follow recommended field and postharvest control measures. Heat treatment of seed roots at 41 to 43°C for 24 h will prevent development of black rot.

Chilling Injury. Brown tinged with black discolored areas scattered or associated with vasculars. The interior becomes pithy. Chilling injury is often produced by exposure to lower temperatures for only a few days. Uncured roots are more sensitive than cured ones. *Control:* Store sweet potatoes at 13 to 16°C.

Freezing Injury. Soft, leaky condition of the flesh. The outer layer of the potato is dark brown. *Control:* Do not subject potatoes to low temperatures; sweet potatoes may freeze at -1°C.

Rhizopus Rot. See [Table 5](#), Note 3. *Control:* Cure potatoes for 4 to 7 days at 29°C before storage. Follow recommended field and postharvest control measures.

Tomatoes (Mature Green, 13 to 21°C; Ripe, 10°C; 90 to 95% rh)

Mature green tomatoes cannot be successfully stored at temperatures that greatly delay ripening, even at a temperature of 13°C, which is considered to be a nonchilling temperature. Tomatoes held for 2 weeks or longer at 13°C may develop an abnormal amount of decay and fail to reach as intense a red color as tomatoes ripened promptly at 18 to 21°C. Temperatures of 20 to 22°C, and a relative humidity of 90 to 95% are probably used most extensively in commercial ripening of mature green tomatoes. At temperatures above 21°C, decay is generally increased. A temperature range of 14 to 16°C is probably the most desirable for slowing ripening without increasing decay problems. At this temperature, the more mature

fruit will ripen enough to be packaged for retailing in 7 to 14 days. Tomatoes should be kept out of cold, wet rooms because, in addition to potential chilling injury, extended refrigeration damages the ability of fruit to develop desirable fresh tomato flavor.

Ethylene gas is sometimes used to hasten and give more even ripening to mature green tomatoes. In ripening rooms, a concentration of one part ethylene per 5000 parts of air daily for 2 to 4 days will usually shorten the ripening period by about 2 days at 20 to 22°C. Some tomatoes are gassed with ethylene in loaded railcars prior to shipping. Adding ethylene has little or no effect on tomatoes just before or after they have started to turn pink. Tomatoes themselves give off considerable ethylene as they ripen. Interest is increasing in the commercial use of low O₂ atmospheres of 3 to 5% during storage or transport to retard ripening and decay.

Storage temperatures below 10°C are especially harmful to mature green tomatoes; these chilling temperatures make the fruit susceptible to *Alternaria* decay during subsequent ripening. Increased decay during ripening occurs following 6 days' exposure to 0°C, or 9 days at 4°C (see [Table 1](#)).

Firm ripe tomatoes may be held at 7 to 10°C with a relative humidity of 85 to 90% overnight or over a holiday or weekend. Tomatoes showing 50 to 75% of the surface colored (the usual ripeness when packed for retailing) cannot be successfully stored for more than 1 week and be expected to have a normal shelf life during retailing. Such fruits should also be held at 7 to 10°C and 85 to 90% rh. A storage temperature of 10 to 13°C is recommended for pink-red to firm red tomatoes raised in greenhouses.

When it is necessary to hold firm ripe tomatoes for the longest possible time, consistent with immediate consumption on removal from storage, such as on board a ship or for an overseas military base, they can be held at 0 to 2°C for up to 3 weeks, with some loss in quality. Mature green, turning, or pink tomatoes should be ripened before storage at this low temperature.

***Alternaria* Rot.** Decayed area is brown to black, with or without a definite margin. Lesions are firm; rot extends into the flesh of the fruit. Dense, velvety, olive green or black spore masses frequently grow over affected surfaces. *Control:* Avoid mechanical injuries at packing time. Avoid temperatures below 10°C in green fruit.

Bacterial Soft Rot. See [Table 5](#), Note 1.

Cladosporium Rot. Thin, brownish blemishes or black shiny spots of shallow decay, later covered by green, velvety mold. *Control:* Take care in harvesting and packing. Ship high quality tomatoes free of field chilling injury under protective services that will provide temperatures of 13 to 20°C.

Late Blight Rot (*Phytophthora*). Greenish brown to brown, roughened areas with a rusty tan margin. *Control:* Apply recommended field control measures. Cull tomatoes carefully before packing.

Phoma Rot. Slightly sunken, moderately penetrating, black areas at the edge of the stem scar and elsewhere on the fruit. Black pimplelike fruiting bodies develop later. Decayed tissues are firm and brown to black in color. Phoma rot is found in eastern-grown tomatoes. *Control:* Apply field control measures. Exercise care in harvesting and packing. Avoid temperatures below 13°C.

Rhizopus Rot. See [Table 5](#), Note 3.

Soil Rot (*Rhizoctonia*). Small circular brown spots, frequently with concentric ring markings; later, large, brown, and fairly firm lesions. In advanced stages, under warm conditions, cream-colored or brown mycelium and irregular sclerotia may develop. *Control:* Before packing, sort out tomatoes with early lesions if the disease is prevalent.

Turnips (0°C and 95% rh)

Turnips in good condition can be expected to keep 4 to 5 months at 0°C with 90 to 95% rh. At higher temperatures (5°C and above), decay will develop much more rapidly than at 0°C. Injured or

bruised turnips should not be stored. Store turnips in slatted crates or bins and allow good circulation around containers.

Dipping turnips in hot melted paraffin wax gives them a glossy appearance and is of some value in reducing moisture loss during handling. However, waxing is primarily to aid in marketing and is not recommended prior to long-term storage.

Turnip greens are usually stored for only short periods (10 to 14 days). They should keep about as well as spinach at 0°C with crushed ice in the packages.

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