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Postharvest Handling Systems: Underground Vegetables (Roots, Tubers, and Bulbs)

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The edible portions of this group of vegetables develop mostly underground and include several botanical structures:

- Roots: beet, carrot, celeriac, radish, horseradish, parsnip, turnip, sweet potato, cassava, jicama
- Tubers: potato, Jerusalem artichoke, yam
- Bulbs: onion, garlic, shallot, and related *Allium* spp.
- Others: ginger rhizomes, taro (dasheen) corms

Vegetables in this group can also be divided into two subgroups based on their postharvest temperature requirements:

- Temperate-zone underground vegetables: beet, carrot, celeriac, radish, horseradish, parsnip, turnip, potato, onion, garlic, shallot, daikon, salsify, water chestnut
- Subtropical and tropical underground vegetables: sweet potato, yam, cassava, ginger, taro, jicama, malanga

The commodities in the underground vegetables grouping have several common characteristics. They are all storage organs, principally of carbohydrates; they generally have low respiration rates (depending on the stage of development); they are considered relatively nonperishable, especially if the tops are removed; they continue growth after harvest (rooting and sprouting); and they can generally be stored for relatively long periods.

HARVESTING

Maturity indices vary with commodity. Many of these products may be harvested and marketed at various stages of development (e.g., "new" or immature potatoes versus mature potatoes; "baby" or immature carrots versus mature carrots). For some mature root and bulb crops, practices such as irrigation management and rolling or chemical destruction of vegetation, may be used to speed up maturation. Criteria commonly used to harvest at the mature stage include:

- Carrot: size, length of root
- Radish: days from planting, size
- Potato: drying of foliage, setting of skins
- Cassava and taro: drying of foliage begins
- Garlic and onion: drying and bending over of tops (fig. 35.1)
- Sweet potato: days from planting, size

Both mechanical and manual harvesting are used for this group of vegetables. Most roots and tubers are harvested mechanically and transported in bulk to packinghouses or processing facilities. Garlic and onion for fresh market are mechanically undercut, hand-harvested and hand-trimmed, cured in the field, and field-packed or transported to packinghouses. Some fresh-market onions are now mechanically harvested in California. Sweet potato harvesting is still done mostly by hand, although vine cutting and lifting are done mechanically. Vine-killing chemicals may be used on potatoes before mechanical harvesting. Carrots are undercut, lifted by their tops, and detopped during mechanical harvest.

Figure 35.1

Onion tops bent over, indicating bulbs are mature and ready for harvest.

Figure 35.2

Stem end of undamaged potatoes (left) and internal discoloration caused by dropping (right).

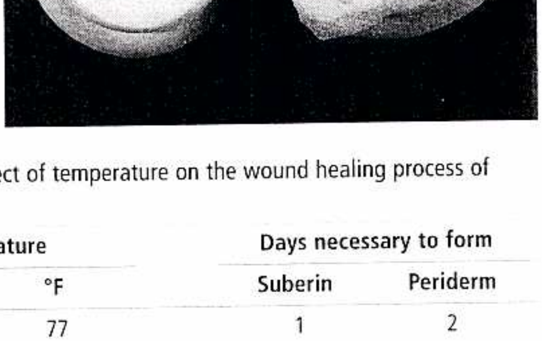


Table 35.1. Effect of temperature on the wound healing process of potatoes

Temperature		Days necessary to form	
°C	°F	Suberin	Periderm
25	77	1	2
15	59	2	3
10	50	3	6
5	41	5–8	10
2	36	7–8	Not formed

Source: Adapted from Burton 1982.

Physical damage during the harvesting operations can be extensive and is a major cause of postharvest losses. The mechanical detopping of carrots often causes nicks on the stem end, and if the carrots are cold and turgid, it can cause longitudinal cracking. Internal bruising of potatoes is a common defect and can occur at all points of handling. The stem end is particularly sensitive to discoloration after dropping injury because it contains high levels of the phenolic compounds that form the undesirable blue-black pigments in the bruised areas (fig. 35.2).

POSTHARVEST PROCEDURES

CURING

One of the simplest and most effective ways to reduce water loss and decay during storage of root, tuber, and bulb crops is curing after harvest. In roots and tubers, curing refers to the process of wound healing, with the development and suberization of new epidermal tissue (wound periderm). The effect of temperature on wound healing in the potato is shown in table 35.1. The type of wound also affects periderm formation: abrasions result in the formation of deep, irregular periderm, cuts result in a thin periderm, and compressions and impacts may entirely prevent periderm formation. Figure 35.3 shows wound healing on sweet potatoes in a commercial storage. In this case, warm product was loaded into the storage and held without ventilation for 1 week to favor curing, then temperature was dropped to storage conditions. Figure 35.4 shows that curing damaged areas of jicama roots prevented development of decay during storage.

In bulb crops, curing refers to the process of drying of the neck tissues and of the outer leaves to form dry scales. Some water loss takes place during curing. Removing decayed bulbs before curing and storage ensures a greater percentage of usable product after storage. When onions and garlic are cured in the field, they are undercut, then hand-pulled. Sometimes the roots and tops are trimmed and the bulbs then are allowed to dry in field racks or bins from 2 to 7 days or longer, depending on ambient conditions (fig. 35.5). Sometimes they are pulled and cured before trimming. Curing may be done in windrows with the tops covering the bulbs to prevent sunburn. Where

Figure 35.3

Cured areas of sweet potatoes damaged during harvest.

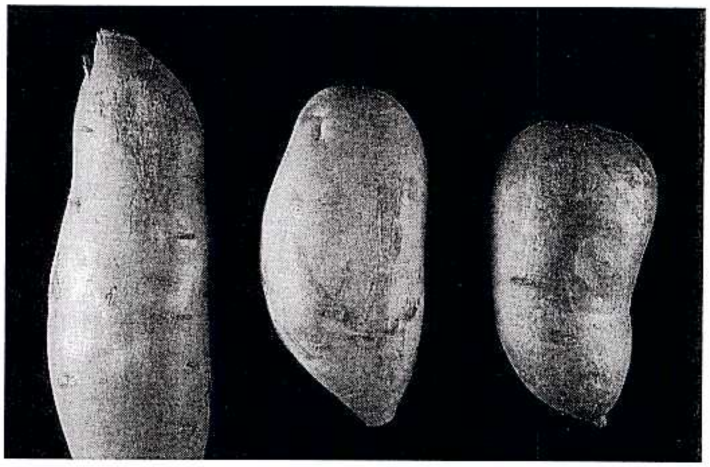


Figure 35.4

Jicama stored at 12.5°C (55°F). Roots were undamaged (left), damaged and not cured (middle), or damaged and cured (right) at 30°C (86°F).

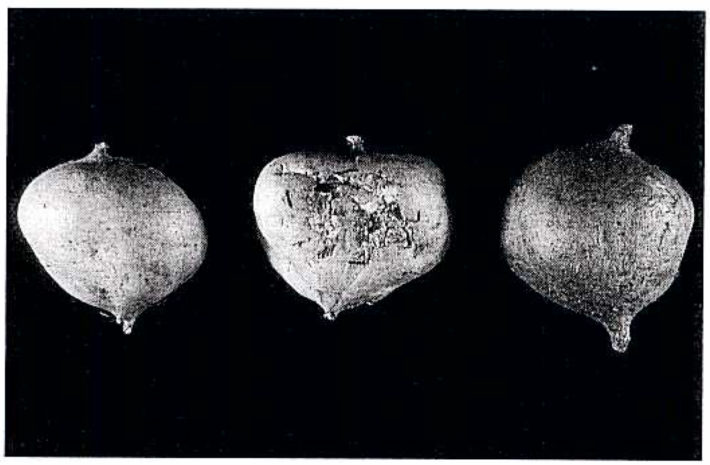
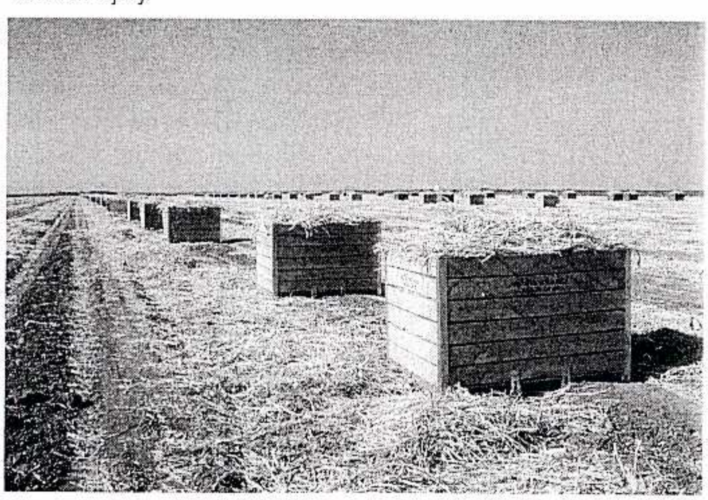


Figure 35.5

Mechanically undercut and manually trimmed garlic for fresh market being field-cured in California. Bins are covered with garlic stalks to prevent sun injury.



ambient conditions are unfavorable, curing may be done in rooms with warm forced air. Onions develop the best scale color if cured at temperatures of 25° to 32°C (77° to 90°F) (fig. 35.6).

Recommended conditions for curing vary according to commodity, as shown in table 35.2.

PREPARATION FOR MARKET

Onion, garlic, potato, and sweet potato are often stored after curing and before preparation for market (cleaning, grading, sizing, and packing). These products, and other root crops such as carrot and turnip, may be stored from 3 to 10 months in mechanically refrigerated or ventilated storages (see discussion on storage conditions and table 35.3).

The following operations are commonly used to prepare root, tuber, and bulb crops for market (figs. 35.7, 35.8, 35.9).

Bin or flume dumping. Water is usually used for roots and tubers to reduce physical injury, but it is not used for bulb crops.

Cleaning. Dry-brushing or washing and partial drying, removing excess moisture.

Sorting. Eliminating defective product and plant debris.

Decay control. Chlorination of wash and flume waters provides sanitation for carrot and potato. Postharvest fungicides are used to a limited extent on some of these commodities, such as sweet potato.

Sizing. Sizing is done mechanically or by hand. Mechanical sizers are generally diverging rollers or weight sizers. Modified volumetric sizers are used for potatoes. Carrots present special sizing problems, since they must be sized by diameter (diverging rollers) and by length (manually or with a gravity-length sizer).

Grading. Separating into quality grades.

Packing. Packing into consumer units (bags, trays) and then into master shipping containers; or bulk-pack into shipping containers (bags, boxes, and bins). Plastic bags are used for products such as carrots that are very susceptible to water loss.

Loading into transit vehicles. Bulk transport to processing plants is sometimes used for onion, potato, and radish. For fresh market, most packed product is palletized, but it may be transferred to slip-sheets for transport in refrigerated trailers. For railcar shipments, sacks are often manually stacked.

Figure 35.6

Curing of field-packed onions under vertical air fans before shipment.

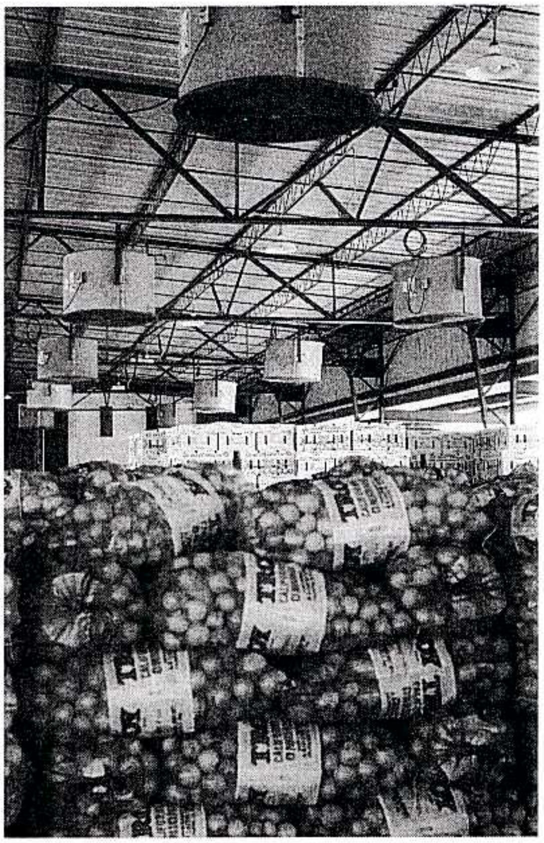


Table 35.2. Conditions for curing root, tuber, and bulb crops

Commodity	Temperature °C	Temperature °F	Relative humidity (%)	Duration (days)
Cassava	30–40	86–104	90–95	2–5
Onion and garlic	30–45	86–113	60–75	1–4
Potato	15–20	59–68	85–90	5–10
Sweet potato	30–32	86–90	85–90	4–7
Yam	32–40	90–104	90–100	1–4

Table 35.3. Storage conditions recommended for tropical root-type vegetables (compiled from various sources)

Commodity	Temperature °C	Temperature °F	Relative humidity (%)	Storage period
Cassava	5–8	41–46	80–90	2–4 weeks
	0–5	32–41	85–95	<6 months
Ginger	12–14	54–57	65–75	<6 months
Jicama	12–15	54–59	65–75	3 months
Sweet potato	12–14	54–57	85–90	<6 months
Taro	13–15	55–59	85–90	<4 months
Yam	13–15	55–59	Near 100	<6 months
	27–30	80–86	60–70	3–5 weeks

COOLING

All temperate-zone root crops except potato, onion, and garlic can be hydrocooled. In areas where potatoes are harvested during hot weather, they may also be hydrocooled as part of the washing operation. These same potatoes are typically room-cooled after packing to 13° to 16°C (55° to 60°F) before shipment. Tropical root crops, onion, and garlic are also occasionally room-cooled before shipment to market.

Potatoes and onions destined for storage are cooled (after curing) during the early phase of the storage period with cool air forced through storage piles or bins. Cooling may be done with cold ambient air or by mechanical refrigeration.

STORAGE CONDITIONS

NONREFRIGERATED STORAGE METHODS

Some growers occasionally store mature potatoes in the ground for several weeks before harvest. Ground storage is also used for several of the tropical and subtropical roots, including cassava and jicama. Pits, trenches, and clamps are used for short-term, small-scale storage of potatoes, sweet potatoes and other root crops.

Ventilated storage in cellars and warehouses is used for potatoes, sweet potatoes, garlic, and onions. Newer facilities with temperature and RH controls provide forced-air circulation through bulk piles of potatoes or onions, or through and around stacks of bulk bins. Ventilation with cool night air can maintain adequate storage temperatures in many areas.

STORAGE OF SUBTROPICAL AND TROPICAL-ZONE ROOT VEGETABLES

The general storage recommendations for tropical-zone root vegetables, summarized in table 35.3, show that most of these products are chilling-sensitive. Symptoms of chilling injury include excessive decay, internal discoloration, and textural changes (e.g., "hard core" in cooked sweet potato and cassava). Figure 35.10 illustrates internal discoloration of jicama due to storage at chilling temperature. Some of these root crops (e.g., cassava) are successfully field-stored but deteriorate rapidly if harvested and held under ambient conditions. Evaporatively

Figure 35.7

Harvest and postharvest handling of root and tuber vegetables.

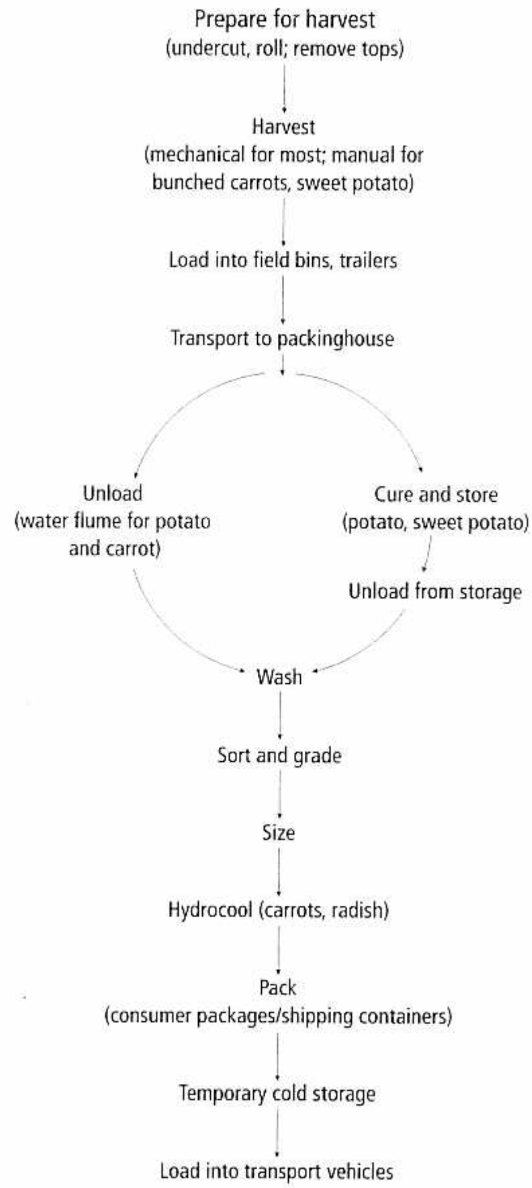
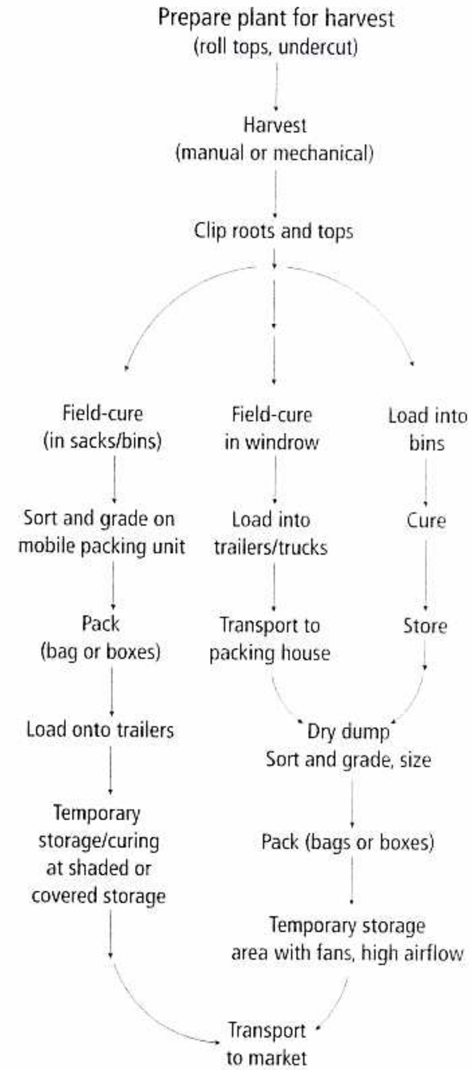


Figure 35.8

Harvest and postharvest operations for bulb vegetables.



cooled storages, which maintain high humidity and moderate temperature (13° to 16°C; 55° to 60°F) conditions, are used in California for storing sweet potatoes for about 9 months.

STORAGE OF TEMPERATE-ZONE ROOT VEGETABLES

In California, temperate-zone root vegetables are not usually stored. When they are stored, the following conditions should be maintained: 0°C (32°F), 95 to 98% RH, and adequate air circulation to remove vital heat from the product and prevent CO_2 accumulation. Beets, carrots, and radishes with tops have a shelf life of only 2 to 3 weeks, whereas these products can be stored several months if the tops are removed.

Potatoes can be stored up to 10 months under proper conditions. Most long-term potato storage facilities are in the northern United States. Because of the long storage periods, weight loss control is very important. In recent years, potato storages have been designed with an "air envelope" exterior to minimize temperature and humidity fluctuations and reduce weight loss.

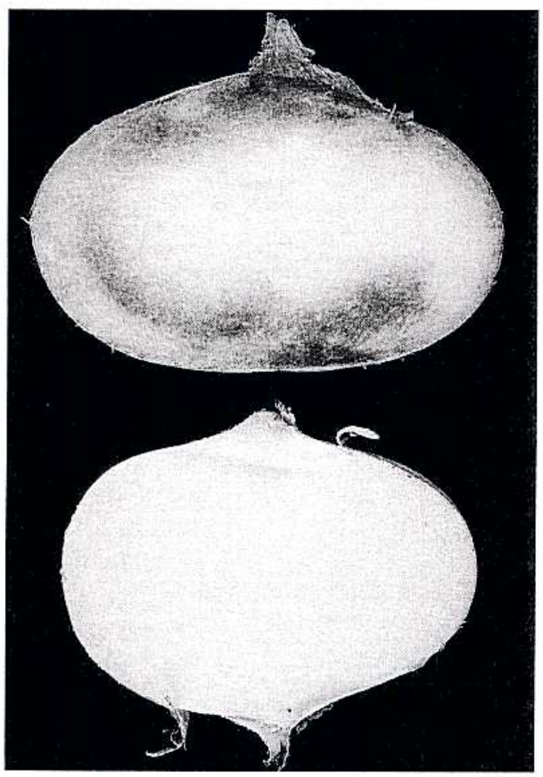
For fresh market, potatoes should be stored under the following conditions: 4° to 7°C (39° to 45°F), 95 to 98% RH, enough air circulation to prevent O_2 depletion and CO_2 accumulation (about 23 l/min per 45 kg, or

Figure 35.9

Mobile packing unit for field-packing of onions.

Figure 35.10

Internal browning of jicama root stored 3 weeks at 10°C (50°F) (top) and 12.5°C (55°F) (bottom). The internal discoloration is one symptom of chilling injury in jicama. The roots did not differ in external appearance.



0.8 ft^3/min per 100 lb of potatoes). For processing (e.g., chipping), the proper conditions are 8° to 12°C (46° to 54°F), 95 to 98% RH, adequate ventilation, and exclusion of light. This higher temperature storage retards undesirable sweetening of the potatoes and consequent dark color of the processed products. Sugars and respiration rates increase during low-temperature storage, indicating that potatoes are slightly chilling-sensitive. Seed potatoes are best kept at 0° to 2°C (32° to 36°F), 95 to 98% RH, with adequate ventilation. In this case low-temperature sweetening is not important, and decay and water loss are minimized. Some potato varieties are more susceptible to chilling injury than others. Storage at very low temperatures over extended periods can result in mahogany browning and cavitation of internal tissues (fig. 35.11). Decay, especially soft rot due to *Erwinia* bacteria, can be a problem during long-term storage of potatoes. Proper curing of harvest wounds on the potatoes before storage is important to reduce decay.

Garlic should be kept at 0°C (32°F) or slightly below for long-term storage (6 to 7 months); 20° to 30°C (68° to 86°F) can be used for storage up to 1 to 2 months. Garlic cloves sprout most rapidly at intermediate temperatures (4° to 18°C; 40° to 64°F). Ventilation of about 1 m^3 of air per minute per cubic meter (1 ft^3 of air per minute per cubic foot) of garlic with 70% RH is adequate.

Onions vary in their storage capability. The more pungent types with high soluble solids contents store longer, whereas mild onions with low soluble solids content are not usually stored for more than 1 to 3 months. Storage temperatures should be either 0° to 5°C (32° to 41°F) or 20° to 30°C (68° to 86°F), as intermediate temperatures favor sprouting. Relative humidity should be maintained at 65 to 70%, and ventilation rate should be from 0.5 to 1 m^3 of air per minute for each cubic meter (0.5 to 1 ft^3 of air per minute per cubic foot) of onions. Avoid light exposure to prevent greening. With long-term storage, the disorder watery scales or translucency can develop (fig. 35.12). Decays associated with *Aspergillus* (black mold), but especially *Botrytis* (gray mold), increase during storage.

MODIFIED ATMOSPHERES

The use of controlled or modified atmospheres for this group of commodities is very limited. Potatoes and carrots are not benefited by MA. Limited commercial CA storage (3% O_2 and 5 to 10% CO_2) of mild types of onions has been used recently. Besides retarding decay, high-CO_2 atmospheres retard sprout development in onions and garlic (fig. 35.13).

Figure 35.11

Severe chilling injury on potato, showing internal browning and cavitation. Potatoes (cv. Yellow Finn) were stored 6 months at about 2°C (36°F).

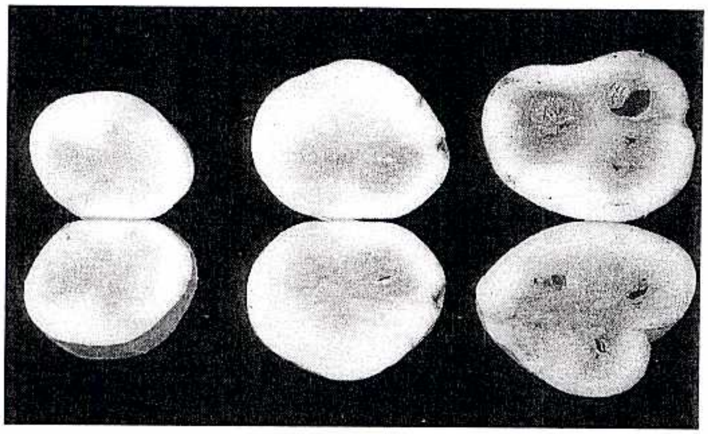


Figure 35.12

Watery or translucent scales of stored onions.

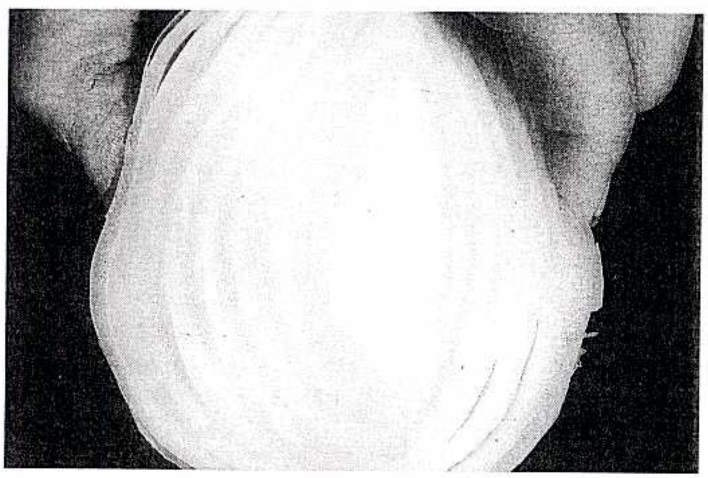
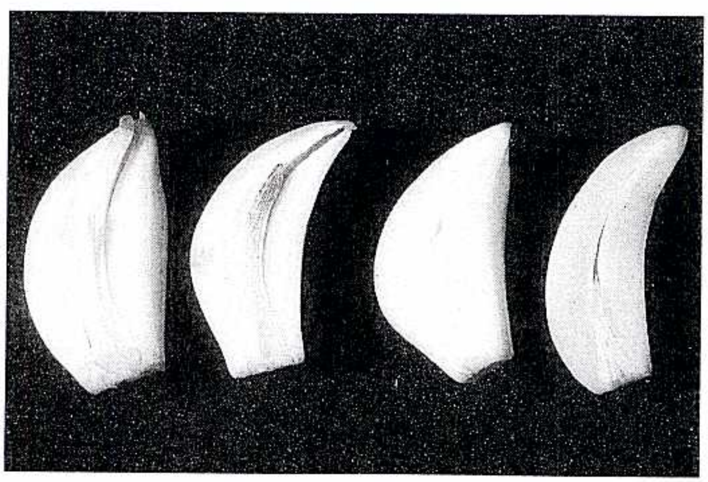


Figure 35.13

Longitudinal sections of garlic cloves stored 5 months at 0°C (32°F) to show sprout development in air (2 cloves on left) or a 0.5% O_2 and 10% CO_2 atmosphere (2 cloves on the right).



ETHYLENE

Most of the products considered in this chapter produce very low amounts of ethylene and are not detrimentally affected by exposure to ethylene. There are important exceptions. Ethylene affects potatoes by stimulating sprout initiation (reduces dormancy), but it then inhibits sprout growth. Ethylene also increases darkening of cooked potatoes. Ethylene is very detrimental to carrots. Low concentrations of ethylene (>0.1 ppm) in the storage environment of carrots and parsnips increase respiration rates and induce the formation of isocoumarin, the compound responsible for bitterness (fig. 35.14). Cut carrot segments, dropped carrots, freshly harvested carrots, and immature carrots develop very high concentrations of isocoumarin and bitterness.

SPECIAL CONSIDERATIONS

SPROUT INHIBITION

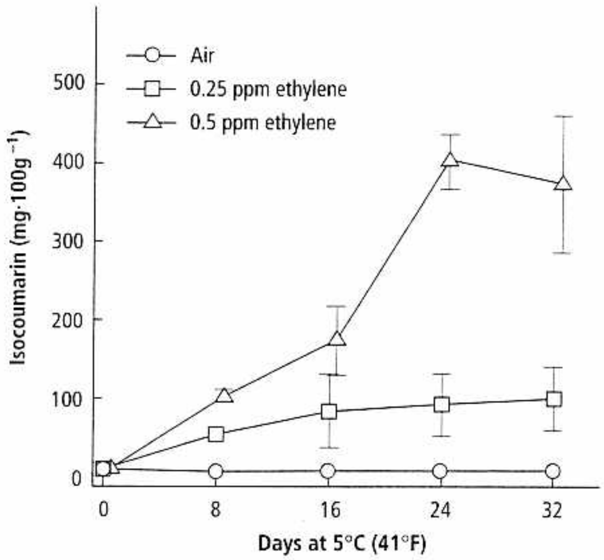
For long-term storage, onions and potatoes (not seed potatoes) are generally sprayed with maleic hydrazide (MH) a few weeks before harvest to inhibit sprouting during storage. Aerosol applications of chlorpropham (CIPC; 3-chloro-isopropyl-N-phenyl carbamate) are often circulated around stored potatoes to further inhibit sprouting. In recent years there have been attempts to look for alternative, naturally occurring sprout inhibitors. Irradiation (0.03 to 0.15 kGy, or 3 to 15 krad, doses) has also been shown to effectively inhibit sprout growth in onions, garlic, and potatoes and is used in some countries.

GLYCOALKALOIDS IN POTATOES

Light needs to be excluded during potato storage and handling to avoid greening. Greening is due to chlorophyll synthesis and is closely associated with accumulation of toxic glycoalkaloids, principally solanine and chaconine. At low levels, these compounds contribute to flavor, but 20 mg alkaloids per 100 g (0.002 oz per 10 oz) (fresh weight) potato is considered the upper safe limit for human consumption. Alkaloids are not destroyed by cooking, and it is therefore necessary to avoid their accumulation. To keep toxic alkaloid content low, potatoes should be stored at low temperatures (<7.5°C, or <45°F), kept away from light, marketed in opaque plastic or paper bags,

Figure 35.14

Development of isocoumarin in young carrots stored at low temperature with low concentrations of ethylene.



and rotated frequently on retail displays. Bruising also stimulates the formation of these alkaloids and is another reason to reduce physical injury to potatoes.

PUNGENCY IN ONIONS

Storage onions have high soluble solids content and high pungency, while the short-shelf-life mild or "sweet" types have low soluble solids and low pungency. Pungency is due to the enzymatic release of sulfur-containing aroma compounds. Onion fields are sometimes sampled for analysis of pyruvate (a by-product of the pungency reactions) to distinguish different qualities of mild onions. Onions with a pyruvate concentration below 5 µm/g fresh weight are considered mild or sweet.

REFERENCES

Booth, R. H., and R. L. Shaw. 1981. Principles of potato storage. Lima: Internat. Potato Center (CIP). 105 pp.

Brewster, J. L., and H. D. Rabinowitch. 1990. Onions and allied crops. 3 vols. Boca Raton, FL: CRC Press.

Brice, J. B., L. Currah, A. Malins, and R. Bancroft. 1997. Onion storage in the tropics: A practical guide to methods of storage and their selection. Chatham, UK: Natural Resources Institute. 119 pp.

Burton, W. G. 1982. Postharvest physiology of food crops. New York: Longman.

———. 1989. The potato. New York: Longman/Wiley. 742 pp.

Cantwell, M., W. Orozco, V. Rubatzky, and L. Herna dez. 1992. Postharvest handling and storage o jicama roots. Acta Hort. 318:333–343.

Clark, C. A. 1992. Postharvest diseases of sweet po toes and their control. Postharv. News and Inf 3:75N–79N.

Cooke, R. D., J. E. Rickard, and A. K. Thompson. 1988. The storage of tropical root and tuber crops—Cassava, yam and edible aroids. Exper. Agric. 24:457–470.

Dale, M. F. B., D. W. Griffiths, and H. Bain. 1998. Effect of bruising on the total glycoalkaloid an chlorogenic acid content of potato (*Solanum tuberosum*) tubers of 5 cultivars. J. Sci. Food Agric. 77:499–505.

Kopsell, D. E., and W. M. Randle. 1997. Onion culti vars differ in pungency and bulb quality chang during storage. HortScience. 32:1260–1263.

Lafuente, M. T., G. López-Gálvez, M. Cantwell, and F. Yang. 1996. Factors influencing ethylene-induced isocoumarin formation and increased respiration in carrots. J. Amer. Soc. Hort. Sci. 121:537–542.

Mazza, G. 1989. Carrots. In N. A. M. Eskin, ed., Quality and preservation of vegetables. Boca Raton, FL: CRC Press. 75–119.

McGee, R. S. 1995. Current state of the art in potatc storages. ASAE Publ. 1-95:538–545.

Prange, R. K., W. Kalt, B. J. Daniels-Lake, C. L. Liew R. T. Page, J. R. Walsh, P. Dean, and R. Coffin. 1998. Using ethylene as a sprout control agent in stored 'Russet Burbank' potatoes. J. Amer. Soc. Hort. Sci. 123:463–469.

Purcell, A. E., W. M. Walter Jr., and L. G. Wilson. 1989. Sweet potatoes. In N. A. M. Eskin, ed., Quality and preservation of vegetables. Boca Raton, FL: CRC Press. 285–304.

Rastorski, A., A. van Es, et al. 1987. Storage of potatoes. Post-harvest behavior, store design, storag practices, handling. Wageningen, Netherlands: Pudoc. 453 pp.

Ravi, V., and J. Aked. 1996. Review on tropical root and tuber crops. II. Physiological disorders in freshly stored roots and tubers. Crit. Rev. Food Sci. Nutr. 36:711–731.

Ravi, V., and C. Balagopalan. 1996. Review on tropical root and tuber crop. I. Storage methods and quality changes. Crit. Rev. Food Sci. Nutr. 36:661–710.

Salunkhe, D. K., B. B. Desai, and J. K. Chavan. 1989 Potatoes. In N. A. M. Eskin, ed., Quality and preservation of vegetables. Boca Raton, FL: CR Press. 1–52.

Schouten, S. P. 1987. Bulbs and tubers. In J. Weichmann, ed., Postharvest physiology of vegetables. New York: Marcel Dekker. 555–581.

Shibairo, S. I., M. K. Upadhyaya, and P. M. A. Toivonen. 1997. Postharvest moisture loss characteristics of carrot (*Daucus carota* L.) cultivars during short-term storage. Scientia Hortic. 71:1–12.

Smith, O. 1977. Potatoes: Production, storing, processing. 2nd ed. Westport, CT: AVI. 776 pp.

Smith, W. L., Jr., and J. B. Wilson. 1978. Market diseases of potatoes. USDA Handb. 479. 99 pp.

Smittle, D. A. 1989. Controlled atmosphere storage of Vidalia onions. In J. K. Fellman, ed., Proc. International Controlled Atmosphere Research Conf. Vol. 2. Moscow: University of Idaho. 171–177.

Snowdon, A. L. 1992. Color atlas of post-harvest diseases and disorders of fruits and vegetables. Vol. 2. Vegetables. Boca Raton, FL: CRC Press. 416 pp.

Stoll, K., and J. Weichmann. 1987. Root vegetables. In J. Weichmann, ed., Postharvest physiology of vegetables. New York: Marcel Dekker. 541–553.

Thompson, J. F., and R. W. Scheuerman. 1993. Curing and storing California sweet potatoes. Davis: Univ. Calif. Dept. Biol. Agric. Engr. 4 pp.

Wilson, L. G., C. W. Averre, J. V. Baird, E. O. Beasley, A. R. Bonanno, E. A. Estes, and K. A. Sorensen. 1989. Growing and marketing quality sweet potatoes. Raleigh: N.C. State Univ Agric. Ext. Publ. AG-09. 28 pp.

Wright, P. J., and D. G. Grant. 1997. Effects of cultural practices at harvest on onion bulb quality and incidence of rots in storage. N.Z. J. Crop Hort. Sci. 25:353–358.