

CHAPTER 21

DECIDUOUS TREE AND VINE FRUIT

<i>Fruit Storage and Handling Considerations</i>	21.1	<i>Peaches and Nectarines</i>	21.12
<i>Apples</i>	21.1	<i>Apricots</i>	21.13
<i>Pears</i>	21.6	<i>Berries</i>	21.13
<i>Grapes</i>	21.8	<i>Strawberries</i>	21.13
<i>Plums</i>	21.11	<i>Figs</i>	21.14
<i>Sweet Cherries</i>	21.12	<i>Supplements to Refrigeration</i>	21.14

THE most obvious losses from marketing fruit crops are caused by mechanical injury, decay, and aging. Losses in moisture, vitamins, and sugars are less obvious, but they adversely affect quality and nutrition. Rough handling and holding at undesirably high or low temperatures increases loss. Loss can be substantially reduced by greater care in handling and by following recommended storage practices.

FRUIT STORAGE AND HANDLING CONSIDERATIONS

Quality and Maturity

Maximum storage life can be obtained only by storing high-quality commodities soon after harvest. Different lots of fruit may vary greatly in their storage behavior due to variety, climate, soil and cultural conditions, maturity, and handling practices. When fruit is transported from a distance, is grown under unfavorable conditions, or is in a deteriorated state, proper storage allowance should be made.

Fresh fruit for storage should be as free as possible from skin breaks, bruises, and decay. These defects reduce the value of the product and may cause rapid deterioration not only of the damaged fruit, but also of the stored fruit nearby. This process occurs because damaged fruit often exhibits increased ethylene production, which can cause rapid ripening of many types of climacteric fruit. For the same reason, it is unwise to store fruit or vegetables having different storage characteristics together; some may emit ethylene, causing a more sensitive crop to ripen prematurely. Natural cooling in well-ventilated storage slows down or halts these processes.

The amount of incipient decay infection, which influences storage potential of grapes and apples, can be predicted in the early storage period. Only lots with good storage potential should be held for late-season marketing.

The maturity of the fruit at harvest time determines the refrigerated storage life and quality of the product. For any given produce, there is a maturity best suited for refrigerated storage. Undermature produce will not ripen or develop good quality during or after refrigerated storage. For many crops, excessively overmature produce deteriorates quickly during storage, although there are some exceptions for late-harvested fruit (in particular, late-harvested kiwifruit). Determination of maturity can be a complex problem. A number of measurements are used depending on the crop; these include penetrometer firmness, color, degree-days since flowering or fruit set, soluble solids, or other physical, chemical or biological tests. In critical cases, a combination of tests may be used.

Handling and Harvesting

Rising handling costs have encouraged the use of bulk handling and large storage bins for many kinds of fruit. Moving, loading, and

stacking bins by forklift trucks must be done carefully to maintain proper ventilation and refrigeration of the product. Bins should not be so deep that excessive weight damages the produce near the bottom.

Mechanical harvesters for fruit frequently cause some bruising. This damage can materially reduce the quality of the produce.

Storage and Transportation

As in storage, losses from deterioration during distribution are affected by temperature, moisture, diseases, and mechanical damage. Gradual aging and deterioration are continuous after harvest. Time in transit may represent a large portion of postharvest life for some commodities, such as cherries and strawberries. Thus, the environment during this period largely determines produce salability when it reaches the consumer.

To prevent undue warming and condensation of moisture, which promote decay and deterioration, fruit-handling systems must be well designed to minimize rewarming and moisture condensation on the product. For example, fruit should not be removed from cool storage and left unattended for significant periods of time before loading and transport in refrigerated vehicles. When the product is removed from cool storage, it should be consumed as quickly as possible or retained at low temperature.

Details on storage and handling of common fruit are given in the following sections. For more information on storage requirements and physical properties of specific commodities, see [Table 1 in Chapter 10](#). [Table 1](#) in this chapter shows recommended controlled atmosphere (CA) and modified atmosphere (MA) conditions for fruit other than apples and pears (Kader 1997). Also see [Table 1 in Chapter 23](#) for guidelines on mixing of produce in storage and transportation.

APPLES

Apples are not only the most important fruit stored on a tonnage basis, but their average storage period is considerably greater than that of any other fruit. The length of storage may be short for early varieties and those going into processing, but cold storage is critical to proper handling and marketing.

Recommended storage temperature depends on the cultivar. For most apple varieties, cool storage at 0 to 1°C is recommended. Specific recommendations for each commercial cultivar are usually available from marketing organizations [or see Kader et al. (1992)].

Storage life of apple varieties depends on harvest maturity, elapsed time and temperature between harvest and storage, cooling rate in storage, and sometimes cultural factors. The best storage potential is usually found in apples that are mature but have not yet attained their peak of respiration when harvested. However, the grower is inclined to sacrifice storage quality for the better color often gained in red varieties by holding them longer on the tree. Even if harvesting begins at the proper time, the fruit picked last may be at an advanced stage of maturity. Such late-harvested apples

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

Table 1 Summary of Controlled Atmosphere Requirements and Recommendations for Fruits Other Than Apples and Pears

Commodity	Temperature Range, ^a °C	Controlled Atmosphere ^b		Commercial Use as of June 1997
		% Oxygen	% Carbon Dioxide	
Apricot	0 to 5	2 to 3	2 to 3	
Avocado	5 to 13	2 to 5	3 to 10	During marine transport
Banana	12 to 16	2 to 5	2 to 5	During marine transport
Blackberry	0 to 5	5 to 10	15 to 20	Within pallet covers during transport
Blueberry	0 to 5	2 to 5	12 to 20	Limited use during transport
Cherimoya and Atemoya	8 to 15	3 to 5	5 to 10	
Cherry, sweet	0 to 5	3 to 10	10 to 15	Within pallet covers or marine containers during transport
Cranberry	2 to 5	1 to 2	0 to 5	
Durian	12 to 20	3 to 5	5 to 15	
Fig	0 to 5	5 to 10	15 to 20	Limited use during transport
Grape	0 to 5	2 to 5 or 5 to 10	1 to 3 10 to 15	Incompatible with SO ₂ Can be used instead of SO ₂ for decay control up to four weeks
Grapefruit	10 to 15	3 to 10	5 to 10	
Kiwifruit	0 to 5	1 to 2	3 to 5	Expanding use during transport and storage; C ₂ H ₄ must be maintained below 20 µg/kg
Lemon	10 to 15	5 to 10	0 to 10	
Lime	10 to 15	5 to 10	0 to 10	
Lychee (litchi)	5 to 12	3 to 5	3 to 5	
Mango	10 to 15	3 to 7	5 to 8	Increasing use during marine transport
Nectarine	0 to 5	1 to 2 or 4 to 6	3 to 5 15 to 17	Limited use during marine transport Reducing chilling injury (internal breakdown) of some cultivars
Olive	5 to 10	2 to 3	0 to 1	Limited use to extend processing season
Orange	5 to 10	5 to 10	0 to 5	
Papaya	10 to 15	2 to 5	5 to 8	
Peach, clingstone	0 to 5	1 to 2	3 to 5	Limited use to extend canning season
Peach, freestone	0 to 5	1 to 2 or 4 to 6	3 to 5 15 to 17	Limited use during marine transport Reducing incidence and severity of internal breakdown (chilling injury) or some cultivars
Persimmon	0 to 5	3 to 5	5 to 8	Limited use of modified atmosphere packaging
Pineapple	8 to 13	2 to 5	5 to 10	Waxing is used to create modified atmosphere and reduce endogenous brown spot
Plum	0 to 5	1 to 2	0 to 5	Limited use for long-term storage of some cultivars
Pomegranate	5 to 10	3 to 5	5 to 10	
Rambutan	8 to 15	3 to 5	7 to 12	
Raspberry	0 to 5	5 to 10	15 to 20	Within pallet covers during transport
Strawberry	0 to 5	5 to 10	15 to 20	Within pallet covers during transport
Sweetsop (custard apple)	12 to 20	3 to 5	5 to 10	

Source: Kader (1997).

^aUsual or recommended range; a rh of 90 to 95% is recommended.

^bSpecific CA combination depends on cultivar, temperature, and duration of storage. These recommendations are for transport or storage beyond two weeks. Exposure to lower O₂ or higher CO₂ concentrations for shorter durations may be used to control some physiological disorders, pathogens, or insects.

do not have good storage characteristics; neither do those harvested on the immature side, but this is seldom a problem with apples intended for storage before marketing. Harvest at proper maturity, careful handling, and prompt storage after harvest are conducive to long storage life.

Chilling injury is the term commonly applied to disorders that occur at low storage temperatures where freezing is not a factor. The exact mutual relationship of the many types of chilling injury is unknown. The principal disorders classed as chilling injuries in apples are (1) soft scald, (2) soggy breakdown, (3) brown core, and (4) internal browning. Varieties susceptible to one or more of these disorders are Rome Beauty, Braeburn, Jonathan, Golden Delicious, Empire, Grimes Golden, McIntosh, Rhode Island Greening, and Yellow Newtown. In addition to variable susceptibility by variety, there are also yearly variations related to climate, fruit size, and cultural factors.

The following practices affect the condition of apples held for both conventional and controlled atmosphere storage:

Maturity. Because there is no reliable maturity index, growers must use personal experience of the variety, area, or orchard to decide when the crop is mature. Availability of labor, size of operation and crop, weather, storage facilities, and intended length of storage also affect the time of harvest.

Handling to Storage. For optimum storage, apples should be cooled within one or two days of harvest because they can deteriorate as much during one day at field temperatures as during one week at proper storage temperature. If other factors prevent final packaging, fruit can be cooled and stored in the field bins used for harvest. In this case, no grading will have been done to remove substandard product. Subsequent grading may result in an increased level of bruising, especially if the fruit is still cold when handled.

Normally, apples are placed in storage and cooled by the room refrigeration equipment to about 0°C in 1 to 3 days. Hydrocooling is sometimes used, but it requires careful disease control. It also interferes with scald inhibitors, which must be applied to the warm fruit.

Controlled Atmosphere Storage

Controlled atmosphere (CA) storage offers important gains in extending the market life of certain apple varieties. Chilling injury is eliminated in some varieties by elevating the storage temperature to about 4°C and altering the composition of the atmosphere.

Only apples of good quality and high storage potential should be placed in CA storage. Harvest maturity and handling practices are crucial; only fruit harvested at proper maturity should be considered. In any one district, this limits the number of apples suitable for CA storage to only a few days' harvest. Immature apples or those retained on the tree to gain better color, as is often done with Delicious and McIntosh, are equally undesirable.

Table 2 lists optimum levels of O₂, CO₂, and temperature for CA storage of apples. It also indicates storage life and whether the specific variety is susceptible to storage scald. This information was obtained from a worldwide survey of postharvest scientists who work on pome fruits.

Chapter 13, Refrigerated Facility Design, discusses systems and methods for achieving specific CA conditions as well as construction techniques and details for the rooms and spaces.

Storage Diseases and Deterioration

Storage problems in apples may be caused either by invading microorganisms or by the fruit's own physiological processes. Physiological disorders, although sometimes resembling rots, are related to biochemical processes within the fruit. Susceptibility to such disorders is often a variety characteristic, but it may be influenced by cultural and climatic factors and storage temperature.

Alternaria Rot. Dark brown to black, firm, fairly dry to dry storage decay centering at wounds, in skin cracks, in core area, or in scald patches—one of the blackest of storage decays. *Control:* Cultural practices that produce apples of good finish and prevent skin diseases and injuries that open the way for infection.

Table 2 Optimum Levels for Controlled Atmosphere Storage of Apples

Cultivar	Country	Region	Optimum O ₂ , %	Optimum CO ₂ , %	Optimum Temperature, °C	Storage Life, months
Alwa	Poland	Skierniewice	1.5	1.5	0 to 3	7
Ampion	Poland	Skierniewice	1.5	1.5	0 to 3	7
Arlet	Poland	Skierniewice	3	5	0 to 3	8*
Bancroft	Poland	Skierniewice	1.5	1.5	0	9
Bellena Roma	Spain	Lleida	3	2.5	0	*
Blanquilla	Spain	Lleida	3	3	0	6 to 7
Bonza	Australia	Victoria	1.5 to 1.8	1	0	*
Boskoop	Belgium	Heverlee	2	0.7	3 to 3.5	6*
Braeburn	Australia	Victoria	1.5 to 1.8	0.8 to 1	1	*
	Belgium	Heverlee	2	1	1	6
	France	St. Remy	1.5	0.8 to 1.2	0.5 to 1	6*
	Italy	Milan	1	1	0 to 1	8 to 9*
	New Zealand	New Zealand	3	1	0.5	6
	South Africa	Stellenbosch	1.5	1.5	-0.5	8 to 9
	United States	Washington	2	<0.5	1.5	*
Bramley's Seedling	United Kingdom	Kent	1	5	4	11*
Cortland	Canada	Nova Scotia	2.5	4.5	3	8 to 10*
	United States	New York	2 to 3	2 to 3% one month, then 5%	2	4 to 6*
Cox's Orange	Belgium	Heverlee	2	0.7	3 to 3.5	5
Pippin	New Zealand	New Zealand	2	2	3	4 to 5
	Netherlands	Wageningen	1.2 to 1.4	<1	4	6.5
	United Kingdom	Kent	1.3	4	3.5	7
Elstar	Belgium	Heverlee	2	1	1	7
	Canada	Nova Scotia	2.5	4.5	0 to 0.5	No data
	Netherlands	Wageningen	1.2	2.5	1.5	7
Empire	Canada	Nova Scotia	2.5	0.5 to 1	1 to 2	No data
	United States	Michigan	1.5	2.5	3	9
	United States	New York	2 to 3	2 to 3	1 to 2	5 to 10
Fiesta	New Zealand	New Zealand	2	2	0.5	6
	Poland	Skierniewice	1.5	1.5	0 to 3	7
Firmgold	Australia	Victoria	1.5 to 1.8	2 to 2.5	0	No data
Fuji	Australia	S. Australia	2	1	0	8*
	Australia	Victoria	2 to 2.5	2	0	*
	Canada	British Columbia	1.2	1	0	9*
	Canada	British Columbia	0.7	2	0	9*
	France	St. Remy	2 to 2.5	1 to 2	0 to 1	7 to 8*
	Italy	Milan	1	1	0	*
	United States	Washington	1	1	1	9*
	United States	Washington	1	1	1	11*
	United States	California	1.5	<0.5	0 to 1	7 to 9*
Gala	Australia	Victoria	1.5 to 2	1	0	*
	Canada	British Columbia	1.2	1	0	6
	France	St. Remy	1.5	2	0 to 1	4 to 5
	Italy	Milan	3	2	1 to 2	6
	New Zealand	New Zealand	2	2	0.5	No data
	Poland	Skierniewice	1.5	1.5	3	7

*Indicates variety of cultivars is subject to storage scald.

Table 2 Optimum Levels for Controlled Atmosphere Storage of Apples (*Continued*)

Cultivar	Country	Region	Optimum O ₂ , %	Optimum CO ₂ , %	Optimum Temperature, °C	Storage Life, months
Gala (<i>continued</i>)	Spain	Lleida	2	2	2	2 to 9
	United States	Washington	1	1	1	4
	Netherlands	Wageningen	1.2	2	1	5.5
Gala-Mondiel	United Kingdom	Kent	1	5	1.5	7*
Galaxy	Australia	Victoria	1.5 to 2	1	0	No data
Gloster	Netherlands	Wageningen	1.2	3	1	7.5
	Austria	Austria	2.25	3	1.5	10
	Canada	Nova Scotia	2.5	4.5	0 to 0.5	10
Golden Delicious	Poland	Skierniewice	1.5	2	0 to 3	7 to 8
	Australia	South Australia	2	1	0	7
	Australia	Victoria	1.5 to 2	1	0	*
	Austria	Austria	2 to 3	3	1.5	9 to 10
	Belgium	Heverlee	2	2	0.5	10*
	Canada	Nova Scotia	2.5	3	0 to 1.5	10
	Canada	British Columbia	1	1.5	0	11
	France	St. Remy	1 to 1.5	2 to 3	1 to 2	7 to 9*
	Israel	Israel	1.2	2	0	No data
	Israel	Israel	1 to 1.5	2	0	No data
	Italy	Milan	1	1.5	0 to 1	8 to 9
	New Zealand	New Zealand	2	2	0.5	6
	South Africa	Stellenbosch	1.5	3	-0.5	9*
	Spain	Lleida	2.5	2.5	0.5	9*
	Spain	Murcia	2 to 3	4	0.5	7 to 8*
	Netherlands	Wageningen	1.1	4	1	8
	United States	Washington	1	2 to 3	1	9
	United States	West Virginia	1	0	0	7 to 9
	United States	Michigan	1.5	3	0 to 1	9
	United States	New York	2 to 2.5	2 to 3	0	8 to 10*
	Australia	South Australia	2	1	0	8*
Granny Smith	Australia	Victoria	1.5 to 1.8	1	1	*
	France	St. Remy	0.8 to 1.2	0.8 to 1	0 to 2	7 to 8*
	Israel	Israel	1.2	3.5	0	No data
	Israel	Israel	0.8 to 1.5	2 to 5	0	No data
	South Africa	Stellenbosch	1.5	0 to 1	-0.5 to 0.5	No data
	Spain	Lleida	2.5	4	2	7 to 8*
	United States	Washington	1	1	1	11*
	United States	California	1.2	1	0.5	8*
	Canada	Nova Scotia	2.5	2.5	3	4*
Gravenstein	Austria	Austria	2	2 to 2.5	2 to 3	No data
	Belgium	Heverlee	2	1.5	1	7
	Canada	Nova Scotia	2.5	0.5 to 1.5	0 to 3	10*
Idared	France	St. Remy	3	3	2 to 4	7 to 8
	United Kingdom	Kent	1.3	4	4	4*
	United States	Michigan	1.5	3	0	9
	United States	New York	2 to 2.5	2 to 3	1	7 to 9*
	Poland	Skierniewice	1.5	1.5	0 to 3	6*
	Australia	Victoria	1.5 to 1.8	1	0	*
Jester	Austria	Austria	2	2	2	10
	Belgium	Heverlee	1	2.5	0.8	9*
	Canada	Nova Scotia	2.5	4.5	0 to 0.5	10
Jonagold	Canada	British Columbia	1.2	1.5	0	9
	Poland	Skierniewice	1.5	2	3	9
	Spain	Lleida	2	3	0.5	5 to 8*
	Netherlands	Wageningen	1 to 1.2	4	1	9*
	United Kingdom	Kent	1.3	4	1.5	6*
	United States	New York	2 to 2.5	2 to 3	0	5 to 7*
Jonagold Red	Australia	Victoria	1.5 to 1.8	1	0	*
	United States	New York	2 to 3	2 to 3% one month, then 5%	2	3*
	United States	New York	2 to 3	2 to 3	0	3*
Jonamac	United States	New York	2 to 3	2 to 3	0	3*
	Australia	South Australia	2	1	0	8*
	Australia	Victoria	1.5 to 1.8	1	1	*
Jonathan	Poland	Skierniewice	3	5	0	7
	United States	Michigan	1.5	3	0	6
	Australia	Victoria	1.5 to 1.8	1	1	*
Lady Williams	Australia	Victoria	1.5 to 1.8	1	1	*
	Australia	South Australia	2	1	0	8*

*Indicates variety of cultivars is subject to storage scald.

Table 2 Optimum Levels for Controlled Atmosphere Storage of Apples (*Continued*)

Cultivar	Country	Region	Optimum O ₂ , %	Optimum CO ₂ , %	Optimum Temperature, °C	Storage Life, months
Law Rome	United States	Michigan	1.5	3	0	9*
	United States	New York	2 to 2.5	2	0	7 to 9*
Ligol	Poland	Skierniewice	1.5	1.5	0	7.5*
Lobo	Canada	Nova Scotia	2.5	4.5	3 to 3.5	No data
Lodel	Poland	Skierniewice	3	5	0	6
Macfree	Canada	Nova Scotia	2.5	4.5	0 to 0.5	4
McIntosh	Canada	Nova Scotia	1.5	1.2	3	8
	Canada	Nova Scotia	2.5	5	1.7 to 3	8
	Poland	Skierniewice	1.5	1	2	8
	United States	Michigan	1.5	3	3	6*
	United States	New York	3	2 to 3% one month, then 5%	2	5 to 7*
McIntosh (not Marshall)	Canada	British Columbia	2.5	4.5	3	8 to 10
McIntosh-Marshall	Canada	British Columbia	2.5	4.5	3	8 to 10
	United States	New York	4 to 4.5	2 to 3% one month, then 5%	2	No data
Melrose	France	St. Remy	2 to 3	3 to 5	0 to 3	4 to 6*
	Poland	Skierniewice	3	5	0	8
Moir	Canada	Nova Scotia	2.5	4.5	0 to 0.5	<2
Mutsu	Australia	Victoria	1.5 to 1.8	1	1	*
	United States	Michigan	1.5	3	0	9*
	United States	New York	2 to 2.5	2 to 3	0	6 to 8*
Nashi (Nijisseki)	Australia	Victoria	1.5 to 1.8	1	1	*
	Australia	South Australia	2	1	0	5
Northern Spy	Canada	Nova Scotia	2.5	2	0 to 0.5	No data
	United States	Michigan	1.5	3	0	12
Nova Easygro	Canada	Nova Scotia	2.5	4.5	0 to 0.5	4
Novamac	Canada	Nova Scotia	2.5	4.5	3 to 3.5	4
Novaspy	Canada	Nova Scotia	2.5	4.5	0 to 0.5	10
Pink Lady	Australia	South Australia	2	1	0	9
	Australia	South Australia	1.5 to 1.8	1	0	*
Prima	Canada	Nova Scotia	2.5	4.5	0 to 0.5	<2
Priscilla	Canada	Nova Scotia	2.5	4.5	0 to 0.5	<2
Boskoop	Netherlands	Wageningen	1.2	0.7	4.5 to 5	5.5*
Red Delicious	Australia	South Australia	1.8 to 2	2 to 2.5	0	*
	Canada	Nova Scotia	2.5	4.5	0 to 0.5	10*
	Canada	British Columbia	1.2	1	0 to 1.1	11*
	Canada	British Columbia	0.7	1	0 to 1.1	11*
	Israel	Israel	1.5	2	0	6 to 9*
	Italy	Milan	0.8	1	0 to 1	8
	Japan	Aomori	2	1.5	0	9*
	New Zealand	New Zealand	1.5	1.5	0.5	6*
	United States	West Virginia	1	0	0	7 to 9*
	United States	Michigan	1.5	3	0	9*
	United States	New York	2 to 2.5	2	0	8 to 10*
	United States	Washington	1	3	1	9*
Red Delicious-Early Red One	Spain	Lleida	2.5	3	0	8*
Red Delicious-Hi Early	Australia	Victoria	2	1	0	8*
Red Delicious-Starking	South Africa	Stellenbosch	1.5	1.5	-0.5	9*
	Spain	Lleida	2.5	2	0	8*
Red Delicious-Topred	France	St. Remy	1.5	1.8 to 2.2	0 to 1	6 to 7*
	South Africa	Stellenbosch	1	1	-0.5	9*
Rome	United States	West Virginia	1	0	0	7 to 9*
Royal Gala	Australia	South Australia	2	1	0	5
	South Africa	Stellenbosch	1	1	-0.5	8
	United States	California	1.5	1.5	0	6
Rubin	Poland	Skierniewice	1.5	1.5	0	7
Runkel	United States	Michigan	1.5	3	0	9
Spartan	Canada	Nova Scotia	2.5	2.5	0 to 0.5	10
	Canada	British Columbia	1.2	1.5	0	11
	United States	New York	2 to 2.5	2 to 3	0	6 to 8*
Splendor	Canada	Nova Scotia	2.5	4.5	0 to 0.5	No data
Sturmer Pippin	New Zealand	New Zealand	2	2	2	4 to 5
Sundowner	Australia	South Australia	2	1	0	9
	Australia	Victoria	1.5 to 2	1	0	*
York	United States	West Virginia	1	0	0	7 to 9*

Source: Mitcham et al. (1997).

*Indicates variety of cultivars is subject to storage scald.

Ammonia Gas Discoloration. Circular spots centering at lenticels; dull green on unblushed side and brown to black on blushed side. Injury may disappear from slightly affected fruit. *Control:* Ventilate as soon as possible. Examine fruit for injury at various points in the room because some sections may escape.

Bitter Pit. Many small, sunken bruise-like spots, usually on the calyx half of the fruit. Masses of brown, spongy tissue occur adjacent to surface pits or may be found deeper in the flesh. In storage, spongy tissue near surface loses moisture and tends to become hollow. New areas may appear and develop in storage. *Control:* Apply boron and calcium, as recommended, in the orchard. Follow cultural practices that promote regular bearing and stabilize moisture. Store fruit of proper maturity and cool promptly to 0°C. Maintain humidity high enough to prevent moisture loss.

Blue Mold Rot (*Penicillium*). Spots of various sizes with decayed tissue that is soft and watery and can be readily scooped out of the surrounding healthy flesh. Rot usually as deep as it is wide. Advanced stages have white tufts of mold that turn bluish-green as spores are produced under moist conditions. Affected tissue has moldy or musty flavor and odor. This is the most prevalent type of storage decay of apples. *Control:* Handle carefully to prevent skin breaks. Cool promptly to 0°C. Use fungicides in wash treatments. Keep picking boxes, packing house, and storage room sanitary. Whitewash walls and ceiling.

Brown Core. No external symptoms. First appears as slight browning or discoloration of core tissue between the seed cavities. Later, part or all of the flesh between the seed cavities and the core line may become brown. Serious in McIntosh and other susceptible varieties stored for long periods at -1°C. *Control:* Pick at proper stage of maturity. Use CA storage at 36 to 3°C. A disorder with similar symptoms has been reported as a result of exposure to excessive concentrations of CO₂.

Freezing Injury. Water-soaked, rubbery condition of large areas or of entire apple. Vasculars (water-conducting strands) brown. Bruised areas in frozen apples large, with wrinkled gray to light brown surface. Moisture lost rapidly from affected areas. In refrigerator cars, most prevalent on floor and at doorways; in storage rooms, most injury in bottom layer boxes, near coils, or against walls next to freezer storage. *Control:* Heat car during subfreezing weather. Prevent cold pockets in storage rooms by adequate air circulation. Minimize handling of fruit while frozen. Thaw at 5 to 10°C. Move thawed fruit into trade channels promptly; do not allow it to become overripe.

Internal Breakdown. Mealy breakdown of internal tissue in overripe fruit. Flesh soft. Surface often duller and darker than normal. Hastened by too high storage temperature, freezing, bruising, or presence of water core, which it often follows. *Control:* Pick before overmature. Cool promptly at temperatures as near 0°C as possible for varieties that tolerate that temperature. Watch ripening rate, particularly of fruit with water core.

Internal Browning. No abnormal skin appearance. Sometimes appears only around core; the apple's outer fleshy portion remains normal in appearance. Occasionally only outer flesh is involved; but when internal browning develops in the outer fleshy portion, it is usually accompanied by browning around the core. Disease develops uniformly throughout tissue. Occurs in firm, sound apples. *Control:* Use CA at 3°C for Empire and other susceptible varieties.

Jonathan Spot. Slate-brown to black, entirely superficial or very slightly sunken, skin-deep spots in color-bearing cells of skin. In some varieties, spots center at lenticels. *Control:* Refrigerate promptly as this disease is greatly aggravated by delayed storage. Use CA storage.

Lenticel Rots. Bullseye rot (*Neofabrabraea*): most common of group; of importance only in apples from Northwest; spots fairly firm, pale centers, decay mealy, may penetrate nearly as deep as wide. Fisheye rot (*Corticum*): tough leathery spot, often follows scab; decayed tissue stringy. Side rots (*Phialophora*): spots shallow

with tender skin, decayed tissue wet, slippery. *Control:* Harvest at prime maturity; store and cool promptly; use forecasting technique for bullseye rot to determine potential keeping quality.

Scab (*Venturia*). Occasionally, active scab spots on fruit at time of storage will enlarge. Fruit may be infected in orchard but show no disease at the time of storage. Disease may subsequently develop in storage as small brown or jet black spots in peel, often without breaking cuticle of fruit. *Control:* Follow recommended orchard spray schedule.

Scald. Diffuse browning and killing of skin of fruit stored for several months. Ordinarily most prevalent on immature fruit or on green portions of fruit. *Control:* Pick apples when well matured. Treat with effective scald-inhibiting chemicals. Scald develops less on fruit in controlled atmospheres.

Soft Scald. Sharply defined or slightly sunken ribbon-like areas in the skin. Affected tissue shallow and rubbery. Most severe on Jonathan, Golden Delicious, and Wealthy. *Control:* Store promptly. Use recommended controlled atmospheres, temperatures, and lengths in storage for each variety.

Soggy Breakdown. Light brown, moist, rubbery, definitely delimited areas in cortex of apple. Not visible on surface. Worst in Grimes Golden, Wealthy, and Golden Delicious. *Control:* Same as for soft scald.

Water Core. Hard, glassy, water-soaked regions in flesh of apple at core or under skin. Decreases in extent during storage but predisposes fruit to internal breakdown. *Control:* Pick as soon as mature. Watch fruit in storage and move before it becomes overripe.

PEARS

Bartlett is the most important pear variety, exceeding the total of all others by a wide margin. Other Pacific Coast varieties are Hardy, Comice, Anjou, Bosc, and Winter Nelis. The eastern states have limited varieties due to the severe problem of fire blight and primarily grow the Kieffer variety. Although most Bartlett and Hardy and many Winter Nelis pears are canned, cold storage prior to ripening for canning is the usual procedure. A 10 day to 2 week cold storage period for Bartlett pears is commonly used by canners because it improves uniform ripening. Substantial quantities may also be stored for periods approaching maximum storage life of the variety to better use processing facilities.

Maturity at harvest has a very important bearing on subsequent storage life, as it does for apples. However, unlike apples, pears do not ripen on the tree, nor do most varieties ripen at cold storage temperatures. If harvested too early, they are subject to excessive water loss in storage. If permitted to become overmature on the tree, their storage life is shortened, and they may be highly susceptible to scald and core breakdown. Flesh firmness as measured by a pressure tester is perhaps the best measure of potential storage life of pears from any single orchard. For the Bartlett variety, a firmness of 85 to 75 N, measured with a Magnus-Taylor pressure tester or similar device, using an 8 mm diameter plunger head, indicates best storage quality. If average firmness is as low as 67 N, storage for any prolonged period is hazardous. Pressure test information for each lot of pears going into storage may be very helpful to both the fruit owner and the cold storage operator in determining the storage program.

Careful harvesting and handling are essential to good storage quality. Bruises and skin breaks are likely sites for infection by microorganisms. Varieties such as Winter Nelis and Bosc are highly susceptible to punctures caused by stems broken in the harvesting operation. Comice is also easily damaged because of its very tender skin. Pears are harvested into pallet bins holding about 450 kg of fruit. Care in dumping fruit from a picking container is important in keeping mechanical damage to a minimum.

For best storage quality, rapid cooling after harvest is essential. Pears ripen rapidly at elevated temperatures but do not soften or change color in the early ripening stages. Therefore, a

considerable part of the storage life may be used up without a visible change in the fruit. If cold storage rooms do not have adequate refrigeration and air circulation capacity for the rapid cooling of fruit, precooling in special rooms (or hydrocooling) before placing in the storage room should be considered. When warm fruit is placed in a room with cold fruit, the loading arrangements should be such that the temperature of the cold fruit is not elevated.

Pears are very sensitive to temperature and should be stored at -1°C and 90 to 95% rh. Recommendations as low as -1.7°C have been made, but the risk of freezing injury is great unless the temperature in all parts of the room can be controlled precisely. Pears are not subject to chilling injury as are some apple varieties, so elevated storage temperatures are not required. The stacking arrangement recommended for apples in the cold storage room also applies for pears.

Table 3 Commercial Controlled Atmosphere Conditions for Pear Varieties^a

Variety	O ₂ , %	CO ₂ , %	Storage, months	CA Disorders ^b
Abate Fetel	1	1	5 to 6	IB
Alejandrina	3	2	4 to 5	IB
Anjou, d'Anjou	1 to 2.5	0 to 0.5	7 to 8	IB, PBC, Cav
Bartlett, (= William's Bon Chretien)	1 to 2	0 to 0.5	3 to 5	CF, PBC
Blanquilla, (= Blanca de Aranjuez)	3	3	6 to 7	
Bosc, Kaiser	1 to 2.5	0.5 to 1.5	4 to 8	PBC, Cav
Buena Luisa	3	2	6	IB, CF
(= Buena Luisa)				
Clapp's Favorite	2	<0.7	3 to 4	IB, PBC
Comice	1.5 to 4	0.5 to 4	5 to 6	IB (overmature)
(= Doyenne du Comice, Comizio)				
Conference	1 to 2.5	0.6 to 1.5	6 to 8	BH, IB, Cav
Coscia	1.5	2 to 3	6 to 7	CF
Flor d'Hivern	3	3	4 to 5	IB
(= Inverno)				
Forelle	1.5	0 to 1.5	6 to 7	
General Leclerc	2 to 3	2 to 3	3 to 5	
Grand Champion	3	2 to 2.5	4	
Hardy	2 to 3	3 to 5	4 to 6	
Josephine	1 to 2	1 to 2	8	
Krystalli	2	1 to 2	3 to 5	
Limonera, Llimonera	3	3	3 to 4	
Packham's Triumph	1.5 to 1.8	1.5 to 2.5	7 to 9	CB
Passe Crassane	3	4 to 5	5 to 8	IB
(= Passa Crassane)				
Rocha	2	2	8	
Spadona	1.5 to 2.5	1.5 to 3.5	8 to 9	IB
Nashi, Asian pears				
Chojuro	2	1 to 2	3 to 4	
Kosui	1 to 2	0 to 2	3 to 4	
Nijiseiki	0.5 to 3	0 to 1	5	
(= 20 th Century)				
Tsu Li	1 to 2	0 to 3	3 to 5	IB
Ya Li ^c	4 to 5	0 to 4	3 to 4	IB, Cav, CI?

Source: Richardson and Kupferman (1997).

^aOptimum storage temperature is -1 to 0°C , unless otherwise indicated.

^bCA disorder abbreviations are as follows:

IB = internal breakdown or browning
 BH = brown heart
 PBC = pithy brown core
 CF = core flush
 Cav = cavity, usually lens-shaped
 CI = chilling injury

^cYa Li may show a type of chill injury at temperatures $<5^{\circ}\text{C}$

Since pears lose water more readily than most apple varieties, good humidity conditions in the storage room must be maintained. For long storage, 90 to 95% rh is recommended. Perforated film box liners are excellent for moisture loss control.

The approximate storage life of pears at -1°C is shown in Table 3. These values assume an additional time for transportation and marketing. If Bartlett pears for canning are harvested at the best stage of maturity and quickly cooled to -1°C , their safe storage life may be as long as 4 months, since marketing involves only ripening for processing. However, quality deteriorates during storage, particularly as the maximum storage life is approached.

After removal from storage, best dessert quality is attained if pears are ripened in a controlled temperature range of about 16 to 21°C . This applies to fruit for the cannery and for fresh use. For cannery fruit, ripening at 20 to 22°C is more practical than at lower temperatures because the shorter time involved reduces overhead costs with no measurable difference in quality.

Controlled Atmosphere Storage

The storage life of Bartlett pears can be extended to 5 to 6 months at -1°C for fruit of desirable maturity (75 to 89 N firmness) in an atmosphere containing 1 to 2% O₂ and 0 to 0.5% CO₂. Bartlett pears of advanced maturity are intolerant to elevated CO₂ and develop core and flesh browning within a few weeks. They are tolerant to low O₂, but have less storage potential than pears of desirable maturity. Chronological age and pressure test (under 71 N firmness) are evidence of advanced maturity.

Commercial storage of pears in a controlled atmosphere has not been considered as necessary as it is in the apple industry. Since no low-temperature disorders have been recognized, there has not been a need for further extension of the storage life.

Table 3 lists optimum levels of O₂ and CO₂, storage time, and CA disorders for varieties of pears at a temperature of -1 to 0°C . This information was obtained via a worldwide survey of postharvest scientists who work on pome fruits.

Many pears from western states, when packed for storage before marketing, have perforated polyethylene liners in the container. While such liners give excellent protection against water loss, there is no agreement as to their value in modifying the atmosphere within the container.

Storage Diseases and Deterioration

The principal storage disorders in pears are (1) core breakdown; (2) scald and failure to ripen; and (3) fungus rots.

Core Breakdown. Often accompanies scald. Soft, brown breakdown in core area having acid, disagreeable odor of acetaldehyde. *Control:* Do not allow pears to become overmature on tree. Cool promptly. Store at -1°C . Ripen fruit between 18 and 24°C .

Core breakdown is associated with overmaturity at harvest. This problem has become more important because of growth regulator sprays used to keep pears from dropping during the harvest season. Pressure test information on late-harvested fruit is helpful in locating lots susceptible to core breakdown. Records of the time lapse between harvest and storage are important, since pressure test information may not be a true measure of relative storage quality where storage is delayed. Pear color, particularly in California Bartletts, is a very poor measure of potential storage life because of great variability among pears from different districts.

Scald. Often accompanies core breakdown. Brown to black softening of large areas of skin and tissues immediately beneath skin. Affected areas slough off readily. Acetaldehyde odor and flavor prominent. *Control:* Pick before overmaturity. Cool promptly. Store only for proper period. Oiled paper wraps do not control scald.

Pear scald is associated with pears that have been stored too long and have lost their capacity to ripen. It is not related to apple scald

and cannot be controlled by any supplemental treatments. The problem develops progressively earlier as the temperature is raised above -1°C . Yellowing of the fruit is the principal storage symptom; Bartlett and Bosc are the two most susceptible varieties. Anjou and Comice may not develop scald but do lose their capacity to ripen. Periodic inspection is desirable to be sure that green pear varieties are removed from storage before yellowing progresses to the danger point. Yellow pears may show no scald in storage but may develop scald on removal to a ripening temperature. If pear scald does show in storage, the pears have been kept too long and may be worthless.

Anjou Scald. Anjou pears are often affected with a surface browning more superficial than common scald and distinct from it, resembling apple scald. Anjou scald is controlled by oiled paper wraps and effective scald-inhibiting chemicals.

Gray Mold Rot (*Botrytis*). Extensive, firm, dull brown, water-soaked decay with bleached border. Dirty white to gray extensive mycelium forming nests of decayed fruit. *Control:* Wrap fruit in copper-impregnated paper. Use fungicide in spray or wax on packing line. Cool promptly to -1°C .

Gray mold rot caused by *Botrytis cinerea* grows at cold storage temperatures and can be a serious threat to long-stored winter varieties such as Anjou and Winter Nelis. Without control measures, the disease may spread from one fruit to another by contact.

Alternaria Rot. Surface is dark brown to black. Decayed tissue is gray to black, dry in center, gelatinous at edge, easily removable as core from surrounding flesh. Found late in storage season, usually at punctures. *Control:* Prevent skin breaks. Remove from storage at first appearance of trouble.

Brown Core. Anjou and Bartlett pears stored in sealed, polyethylene-lined boxes with inadequate permeability may show various degrees of pithy brown core and desiccated air pockets. Prolonged storage in concentrations of 4% or more CO_2 often produces brown core, particularly when pears are harvested at advanced maturity or are cooled slowly after packing. *Control:* Harvest at proper maturity. Cool promptly. Store at -1°C . Use perforated film liners to maintain CO_2 level at 0 to 0.5%.

Freezing Injury. Bartlett and Anjou pears exposed for 4 to 6 weeks just below their freezing point develop glassy, water-soaked external appearance with tan pithy area around core. Pears frozen sharply may break down completely or show abruptly sunken large pits where slightly bruised while frozen. *Control:* Keep transit and storage temperature above -1°C .

GRAPES

Grapes are widely grown in the United States, but over 90% are grown in California. This state produces grapes of the *Vitis vinifera* species almost exclusively. This species can withstand the rigors of handling, transport, and storage required of table grapes for wide distribution over a long marketing period. Almost all of this fruit is pre-cooled and much of it stored for varying periods before consumption. On the other hand, for fresh use, the fruit of the species *Vitis labrusca* (Eastern type) is largely limited to local market distribution.

Grapes grow relatively slowly and should be mature before harvest because all of their ripening occurs on the vine. **Mature** here means that stage of physiological development when the fruit appears pleasing to the eye and can be eaten with satisfaction. However, grapes should not be overripe, as this predisposes them to two serious postharvest disorders: (1) weakening of the stem attachment in some varieties, such as Thompson seedless, which causes the berries to separate from the pedicel attachment; and (2) progressively greater susceptibility to invading decay organisms. Danger of fruit decay is increased with exposure to rain or excessively damp weather before harvest (conditions favorable for the inception of field infections by *Botrytis cinerea* Pers.).

Cooling and Storage

Grapes are vulnerable to the drying effect of the air because of their relatively large surface-to-volume ratio, especially that of the stems. Stem condition is an important quality factor and an excellent indicator of the past treatment of the fruit. Stems should be maintained in a fresh green condition not only for appearance but because they become brittle when dry and are apt to break. The stem of a grape cluster, unlike that of other fruit, is the handle by which the fruit is carried; if breakage (shatter) occurs, the fruit is lost for all practical purposes even though the shattered berries may still be in excellent condition. Therefore, careful attention should be paid to those operations that minimize moisture loss.

The rate of water loss is especially high before and during pre-cooling because grapes are normally harvested under hot, dry conditions. Field heat should be removed promptly after the fruit is picked to minimize the exposure of grapes to low-vapor-pressure conditions. Volume and temperature of the pre-cooling air, velocity of the air past or through the containers (lugs), and accessibility of the fruit to this air are significant factors in the rate of heat removal. These factors are drastically influenced by the location and amount of venting of the containers, alignment of the containers (air channels), and packing materials such as curtains, cluster wraps, and pads.

Table grapes are initially cooled with a forced-air cooling system. A pressure gradient is set up so that there is a positive flow of cold air through the fruit from one vented side of the container to the other. The containers are arranged so that the air must pass *through* the containers before returning to the refrigeration surface. Pre-cooling time is usually 3 to 12 h, depending on the packaging system and airflow.

The recommended storage temperature for *Vitis vinifera* (European or California type) grapes is -1°C . The relative humidity should be 90 to 95%. Although temperatures as low as -1.7°C have not been injurious to well-matured fruit of some varieties, other varieties having low sugar content have been reported damaged by exposure to -0.5°C . Grape storage plants in California should provide uniform air circulation in the rooms. Fruit should be forced-air cooled to less than 4°C before storage. During the initial storage period, a well-distributed airflow of 52 L/s per tonne of grapes is needed to finish the cooling. After the fruit has been pre-cooled, the air velocity should be reduced to a rate that maintains uniform temperatures throughout the room (no more than 0.05 to 0.1 m/s in the channels between the lugs).

The greatest change that takes place in grapes in storage is loss of water. The first noticeable effect is drying and browning of stems and pedicels. This effect becomes evident with a loss of only 1 to 2% of the mass of the fruit. When the loss reaches 3 to 5%, the fruit loses its turgidity and softens.

Maintaining a relative humidity of 90 to 95% in grape storage is often a problem, especially at the beginning of the storage season when the rooms are being filled with dry lugs. Each lug will absorb 0.15 to 0.3 kg of water over a month, and, unless moisture is supplied to the room, this water must come from the fruit. Spray humidification is an effective method of supplying water to minimize shrinkage. With proper balance of water and air pressure and the correct type of nozzle, a fine spray can be obtained that will vaporize readily even at -0.5°C .

Fumigation

Vinifera grapes must be fumigated with sulfur dioxide (SO_2) after they are packed to prevent or retard the spread of decay. The treatment surface-sterilizes the fruit, particularly wounds made during handling.

Fumigation with SO_2 in storage prevents new infections of the fruit but does not control infections that have already occurred in the vineyard. Frequently, these have not developed far enough to be

detected at harvest and consequently are the primary cause of decay in storage. A method of measuring field infection has been developed and used to forecast decay during storage. The forecast indicates the lots that are sound and can be safely stored and also those that are likely to decay and should be marketed early (Harvey 1955, 1984).

It has become common practice during the initial cooling operation to fumigate the fruit in the evening. In this way, precooling is not delayed, and fumigation can be done after most of the working crew has left. This initial treatment often becomes the responsibility of the refrigeration personnel.

Amount of Sulfur Dioxide. Other commodities should not be treated along with the grapes or even held where the fumigant can reach them, as most of them are very easily injured by the gas. Because grapes also can be injured, they should be exposed to the minimum quantity of SO₂ required, which depends on the following:

- Decay potential and condition of the fruit
- Amount of fruit to be treated
- Type of containers and packing materials
- Air velocity and uniformity of air distribution
- Size of the room
- Losses from leakage and sorption on walls

Much of the following information on sulfur dioxide fumigation methods of table grapes is from *Bulletin* 1932, University of California Division of Agriculture and Natural Resources, 1992.

The amount of SO₂ for effective control of *Botrytis* varies with the length of time that grapes are exposed to the gas. The dosage of SO₂ to kill *Botrytis* spores or mycelia during fumigation is 100 mg/kg hours.

Two methods currently used for fumigation are the traditional method and the total utilization method. Both give adequate decay control but differ in the quantity of SO₂ used and the application method.

Traditional fumigation may be used for initial fumigation when grapes are received at a facility, and for weekly fumigation during long-term storage. Relatively high SO₂ concentrations are added for 20 to 30 min, then the remaining gas is scrubbed or vented from the room.

Traditional initial fumigation can be done using either of two airflow systems: circulating-air fumigation or forced-air fumigation. Each is used either in combination with initial cooling or as a separate operation. In **circulating-air fumigation**, air flows past, but not through, palletized boxes. Penetration of SO₂ into the innermost boxes depends on the speed of air past the pallets and the types of box and packing materials. A minimum airspeed of 0.7 m/s is required for maximum penetration.

Airflow systems for **forced-air fumigation** are the same as systems used for forced-air cooling. Sulfur dioxide gas is introduced into the room air and forced through the boxes, resulting in rapid and thorough penetration, even for bagged or tissue-wrapped fruit.

Airflow for many forced-air fumigation rooms is typical of forced-air coolers (about 1.0 L/s per kg of product stored); however, good SO₂ penetration has been observed even in a forced-air cooler with lower airflow (0.5 L/s per kg) and slower cooling times.

The maximum permitted SO₂ concentration for initial fumigation is 10 000 mg/kg. Although a few operators regularly use this level in small circulating-air fumigation chambers, many operators use 5 000 mg/kg for initial fumigation. Levels used for a particular facility must be determined by using SO₂ dosimeter tubes to measure actual SO₂ penetration into boxes.

The amount of SO₂ needed for a traditional fumigation can be calculated by

$$W_s = \frac{A \times V \times C}{10^6}$$

where

W_s = quantity of SO₂ required, kg

A = 0.27 kg SO₂/m³ at 21°C and 0.29 kg SO₂/m³ at 0°C

V = room volume, m³

C = desired SO₂ concentration, mg/kg

Sulfur dioxide concentration may also be expressed in terms of the percentage of SO₂ in the room atmosphere (1% equals 10 000 mg/kg; 0.5% equals 5000 mg/kg).

New fumigation facilities may be restricted from releasing any SO₂ into the outside atmosphere. Water scrubbing can remove SO₂ from the room atmosphere without venting. The most effective systems route refrigeration return air through a water spray or pad assembly. Water can absorb SO₂ at a rate of 0.86 kg SO₂ per 1000 L H₂O, if the water is at 0°C and becomes completely saturated with the fumigant. At 21°C, water will absorb only half as much sulfur dioxide.

Because absorption efficiency drops as water nears saturation with SO₂, the actual amount of water used in practice will be several times the theoretical amount. This water cannot be reused, and must be disposed of. Sodium hydroxide or potassium hydroxide can be added to the scrubber water to increase the amount of SO₂ it can absorb. For large storage rooms, the portable scrubbers used by some operators often require long periods of operation to yield adequate fumigant level reductions. If not maintained, their efficiency can be reduced dramatically by sulfite salts (plugged nozzles are a common problem).

Traditional storage room fumigation is done weekly to prevent the spread of decay from *Botrytis*-infected fruit. Traditional fumigation in cold-storage rooms is similar to traditional circulating-air initial fumigation. The maximum permitted SO₂ concentration for storage fumigation is 5000 mg/kg (EPA 1989), although many operators use 2500 mg/kg to fumigate filled storage rooms, and lower levels for partially filled rooms.

Traditional storage fumigation has a number of disadvantages. Large rooms are required and poorly designed airflow systems and/or nonuniform placement of grape pallets can cause even lower levels of SO₂ penetration and greater variations than in initial fumigation. The short fumigation time results in high SO₂ levels in room air at the end of fumigation; excess fumigant must be vented or scrubbed before the room is safe for reentry.

In **total utilization fumigation**, the amount of SO₂ applied is balanced with the amount absorbed by fruit, boxes, and the room itself. Because fumigation is prolonged and the quantity of fumigant is calculated so closely, nearly all of the SO₂ is absorbed by fruit, packaging materials, and room surfaces. At the end of fumigation, the SO₂ concentration in the room air is usually less than 2 mg/kg.

Total utilization initial fumigation can *only* be used with precooling. For complete gas absorption, the gas must be kept in contact with the product and room surfaces for at least a few hours. Without precooling, the grapes would be exposed to warm air, which would desiccate the stems. Waiting several hours for a drop in SO₂ concentration would also result in an unnecessary delay in cooling. With simultaneous fumigation and precooling, the fruit is quickly cooled and effectively fumigated. Forced-air total utilization initial fumigation may use 75% less SO₂ than traditional fumigation, and consistently provides an in-box CT in excess of 100 mg/kg-hours in all package types. CT is the SO₂ concentration in mg/kg times the exposure time in hours. Airflow considerations for traditional initial fumigation also apply to total utilization initial fumigation with circulating air.

The quantity of SO₂ required for effective decay control can be calculated using the following equation and the factors listed in [Table 4](#).

$$W_s = \frac{B \times Q \times R}{10,000}$$

where

- W_s = quantity of SO₂ required, kg
 B = SO₂ factor from Table 4 (kg of SO₂ per 10 000 boxes)
 Q = quantity of boxes in room
 R = ratio of actual box count to maximum box count in room (R should equal 0.5 if box count drops below 50% of room capacity)

Each box stored occupies from 0.07 to 0.1 m³ of room volume. Calculations are based on a box occupying 0.085 m³ of room volume (10 000 boxes in a 850 m³ room).

Because polystyrene does not absorb sulfur dioxide as readily as wood and fiberboard materials, expanded polystyrene (EPS) boxes have lower SO₂ factors than wood-paper laminated (TKV) boxes. Although there are no reliable industry data on which to base factors for fiberboard boxes, laboratory studies show that they absorb more SO₂ and would have higher factors than TKV boxes. The higher factors ("poor SO₂ penetration" in Table 4) should be used for boxes that have low SO₂ penetration rates due to poor venting or packing materials that reduce gas movement into the box. Grapes with a high potential for decay may also require high SO₂ levels.

As rooms are emptied of grapes, the minimum amount of SO₂ needed is influenced by the absorption by room surfaces and coils and the amount of air leakage. The amount of SO₂ used should not be less than that required for a half-full room. Because initial fumigation rooms may differ in construction and operation, each room must be calibrated to determine the SO₂ quantity needed for a CT of 100 mg/kg-hours in packed boxes.

The procedure for total utilization storage-room fumigation is similar to that described for total utilization initial forced-air fumigation: the SO₂ flows past the outside surfaces of palletized boxes rather than being forced through the boxes. Lanes of pallets are usually stacked 2 to 3 pallets high with 100 to 150 mm between lanes.

The amount of SO₂ required for effective decay control is calculated by the same methods as for total utilization forced-air fumigation. However, SO₂ penetration into boxes can be much poorer in a storage room than in an initial fumigation room, so the SO₂ factors are greater (Table 5). The amount of SO₂ should never be below that required for a half-full room. Higher factors should be used for boxes with poor SO₂ penetration characteristics due to poor venting, overpacking with fruit, or packing with materials that reduce air movement through the box.

Table 4 Factors for Determining Amount of SO₂ Needed for Forced-Air Fumigation Using Total Utilization System

Box Type ^b	SO ₂ Factor, kg/10 000 boxes ^a	
	Good SO ₂ Penetration	Poor SO ₂ Penetration
EPS	0.7	1.4
TKV	1.7	2.9

Source: University of California (1992)

^aFactor is based on boxes that weigh 9 to 11 kg gross.

^bFiberboard boxes should probably be fumigated using the higher TKV factors, although there are no industry data available to make a reliable recommendation.

Table 5 Factors for Determining Amount of SO₂ Needed for Storage Room Fumigation

Box Type ^b	SO ₂ Factor, kg/10 000 boxes ^a	
	Good SO ₂ Penetration	Poor SO ₂ Penetration
EPS	1.4	3.4
TKV	2.9	6.4

Source: University of California (1992)

^aFactor is based on boxes that weigh 9 to 11 kg gross.

^bFiberboard boxes should probably be fumigated using the higher TKV factors, although there are no industry data available to make a reliable recommendation.

EPS and TKV boxes should be stored in separate rooms, as should wrapped, plain-pack, and bagged grapes. Even so, because of the great variability in SO₂ penetration among boxes of the same type, there is still potential for differences in decay control and residue levels in a room filled with similar boxes.

Fans should always be on high speed during the first 1 to 2 h of fumigation, and airspeeds past all pallets should be greater than 0.7 m/s. Pallets should be stacked neatly with a 100 to 150 mm gap between lanes so that airflow is not blocked.

Calibration. All storage rooms should be monitored to determine the effectiveness of the fumigation program by conducting CT, residue, and *Botrytis*-control tests as follows:

- **CT.** A CT of at least 100 mg/kg-hours should be indicated by dosimeter tubes placed among the grapes in boxes located in the hardest-to-fumigate positions in the room (typically, center boxes located in pallets in areas with the least airflow). Dosimeter tubes should be placed in the boxes immediately before fumigating and removed and read at the completion of fumigation. Excessive SO₂ usage is indicated if all dosimeter tubes have a color change along their entire length.
- **Residues.** Residue analyses should be conducted on grapes removed from the easiest-to-penetrate positions. High-residue areas (typically top corner boxes in the highest-airflow areas) can be located by using dosimeter tubes. Because of the variability of residue analysis, residues in excess of 3 mg/kg SO₂ should be viewed with concern.
- ***Botrytis* control.** Grapes stored for a prolonged period should be inspected for the number of *Botrytis*-infected berries. Initial fumigation kills the spores of this fungus. Fumigated rooms are nearly sterile; living *Botrytis* spores are not present in the atmosphere in these rooms. Infected berries found later during storage result from infections initiated in the field. Inadequate fumigation and temperatures above 1.7°C during cold storage after initial fumigation allow mycelial development, and berry-to-berry spread (nesting).

Frequency of storage-room fumigation. Storage rooms should be fumigated frequently enough to control mycelia from infected berries before they can spread to adjacent berries. The speed of mycelium growth varies with temperature. Berry temperature during storage should be as close as possible to -0.5°C. Regular SO₂ fumigation is necessary to control the spread of *Botrytis* from existing infected berries. Industry experience and recent test results indicate that a maximum fumigation interval of 7 days is adequate for this purpose. Lengthening the fumigation interval may lead to a greater amount or spread of decay.

Precautions. Sulfur dioxide has certain properties that demand care in its use as a fumigant in cold storage plants. The concentrations recommended for the fumigation of grapes in storage can cause respiratory spasms and death if the victim cannot escape the fumes. When working in even weak concentrations of SO₂, goggles to protect against injury to the eyes and a gas mask fitted with canister for acid gases (not the usual canister for ammonia gas) should be worn. Concentrations as low as 30 to 40 mg/kg can be detected by smell. It requires several times these concentrations to cause discomfort.

Because a small segment of the population may experience severe allergic reactions to sulfites, the U.S. Environmental Protection Agency has proposed a 10 mg/kg tolerance for sulfite residues in table grapes (EPA 1989, Harvey et al. 1988). Fruit with residues exceeding the tolerance cannot be marketed.

Another precaution about SO₂ that cannot be overemphasized is its injurious effects on other produce. For this reason, care must be taken that only grapes are stored in the room that is to be fumigated and that there are no leaks through walls or halls to adjacent rooms storing other produce.

Periodic inspection of the fruit is recommended to check whether the SO₂ gas is reaching the center of the stacks or whether some

grapes are being overtreated. If the pedicels and stems retain a yellow or green color and broken berries show no mold and appear to be dried or seared, the gas has reached the fruit in question and is having the desired effect. Serious bleaching on unbroken grapes means too high a concentration or too long an exposure; there should be better distribution of the gas, lower concentration, or shorter fumigation periods.

Diseases

Blue Mold Rot (*Penicillium*). Watery, mushy condition. Early production of typical bluish-green spores on berries and stems. Moldy odor and flavor. *Control:* Prevent deterioration in fruit by careful handling and prompt refrigeration, preferably to 0°C. Fumigate with SO₂ in storage.

Cladosporium Rot. Black, firm, shallow decay which produces an olive-green surface mold. Common on stored grapes harvested early in the season. Infections occur on small growth cracks at the blossom end and sides of the grape. *Control:* Precool and store grapes promptly at 0°C. After harvest, fumigate with SO₂ to reduce spread.

Gray Mold Rot (*Botrytis*). Early stage: slip skin with no mold growth. Later, nest of fairly firm decay covered with abundant fine gray mold and grayish-brown, velvety spore masses. *Control:* Cull out decay when packing. Fumigate grapes with SO₂. For storage, cool grapes rapidly to -1°C. Use forecasting technique to determine safe storage periods. Use short storage period for grapes harvested in rainy periods or after slight freezes.

Rhizopus Rot. Soft, mushy, leaky decay causing staining of lugs. Coarse extensive mycelium and black sporangia develop under moist conditions. *Control:* Prevent skin breaks. Cool promptly to below 10°C.

Sulfur Dioxide Injury. Bleached sunken areas on berry at skin breaks or cap-stem attachment. Decolorized portions have disagreeable astringent flavor. Does not appear in full severity until cool grapes are warmed. *Control:* Apply proper concentration and distribution of gas for recommended period.

Storage Life

The normal storage life of the principal varieties of California table grapes at -1°C is shown in Table 6. Under exceptional conditions, sound fruit will keep longer than indicated; for example, Emperor grapes have been held in good condition for 7 months, and Thompson seedless for 4 months.

The storage life of grapes is affected most by the attention given to selecting and preparing the fruit. Grapes should be picked at the best maturity for storage, especially Thompson seedless and Ohanez. Stems and pedicels should be well developed, and the fruit should be firm and mature. Soft and weak fruit should not be stored. The display lug is a satisfactory package for storage since it can be cooled and fumigated easily.

Table 6 Storage Life of California Table Grapes at 0°C

Variety	Storage Life, Months
Emperor, Ohanez, Ribier	3 to 5
Malaga, Red Malaga, Cornichon	2 to 3
Thompson seedless, Tokay	1 to 2.5
Muscat, Cardinal	1 to 1.5

Table 7 Storage Life of *Labrusca* Grapes at 0°C

Variety	Storage Life, Weeks
Catawba	5 to 8
Concord, Delaware	4 to 7
Niagara, Moore	3 to 6
Worden	3 to 5

Cooling to 4 to 7°C is advised for grapes that are to be in transit a day or two before reaching storage. Special care should be taken during transit so that decay does not start. It is not good practice to delay fumigation until the grapes reach a distant storage plant, for in the picking and packing of grapes, many berries are injured sufficiently to permit mold to begin unless the fruit is fumigated promptly.

For *labrusca* (Eastern type) grapes, a storage temperature of 0°C and humidity of 85% are recommended. Care in packing and handling the fruit, a minimum of delay before storage, and prompt cooling are important for best results with these varieties, as they are with the *vinifera* grapes. The Eastern varieties are not fumigated with SO₂ due to their susceptibility to injury from it. The storage life of the important commercial varieties at 0°C is shown in Table 7.

Refrigeration System Materials and Practices

SO₂ is corrosive to many materials; the following materials and practices are recommended to provide satisfactory equipment durability and economical operation:

Evaporators

- Coils: an aluminum alloy resistant to SO₂; also can be coated with a material to prevent chemical attack
- Housing: aluminum sheet metal with 304 stainless steel fasteners
- Fan blades: cast aluminum or mild steel coated with a baked-on food-grade powder coating
- Fan guards: mild steel coated with a baked-on food-grade powder coating
- Fan motors: totally enclosed fan-cooled (TEFC) or total enclosed air-over (TEAO) with cast-iron or cast-steel housing. Specify a high-quality paint job.
- Fan motor shafts: coat with a nickel-based anti-seize material
- Coil connections: use dielectric connectors between the coil connections and the external piping

Piping to Evaporators

- Use aluminum or stainless steel pipe of correct mass or schedule for the refrigerant. Use stainless steel pipe hangers and hanger rods.
- Locate hand valves and control valves outside the cold storage space to minimize corrosion and for ease of maintenance.
- Locate evaporators as close to outside walls as practical to minimize the length of piping between the control valves and the evaporators.
- Revert to piping materials normally used when the piping is outside the cold storage environment. Use dielectric connections between dissimilar materials.

Maintenance and Operation

A successful SO₂ fumigation program requires that the cold storage facilities be well operated and maintained. Leaky door seals, inoperative SO₂ input lines or fans, improperly functioning or unsafe refrigeration equipment, or poorly operating and maintained ductwork reduce the system and program effectiveness. Safe, efficient operations require that equipment and buildings be kept in good working order.

PLUMS

Plums are not suitable for long storage. Commercial storage life varies from 1 to 8 weeks, depending on variety. The Italian Prune can be held for no more than 2 weeks before marketing begins.

Plums intended for storage should be harvested at a high soluble solids level for the variety, although doing so may delay the harvest beyond the normal picking date. Harvested fruit should be carefully graded to remove disease, defects, and injuries before packing in the shipping container.

The fruit should be thoroughly cooled before storage. Forced-air or hydrocooling may be done in the 400 to 450 kg bulk bins that are used for harvest. The shipping containers are normally vented to aid cooling after packing. Although most fruit is air cooled in conventional room coolers, some shippers use forced air to cool fruit quickly in bulk bins or shipping containers.

Many varieties of plums can usually be stored for 1 month at -1 to 0°C with 90 to 95% rh. Results of storage life tests have been varied, with some lots in certain seasons remaining in good condition even after 4 to 5 months in storage. Other lots in some seasons have not been held satisfactorily beyond 2 months. Fruit with the highest soluble solids has consistently shown the longest storage life, even when harvested several weeks after the completion of commercial harvest. Some plum varieties benefit from CA storage.

Storage Diseases and Deterioration

Plum deterioration appears as changes in appearance and flavor. A poststorage holding period should be used in judging the condition of stored fruit. Fruit that appears bright and flavorful in storage can show severe deterioration when removed to room temperature for 2 to 3 days.

Some flesh softening and a gradual loss of varietal flavor and tartsness occur even at low storage temperatures. The first visual sign of deterioration is the development of translucence, first around the pit, then extending outward through the fruit. Translucence is followed by the development of progressively more severe flesh browning following the same pattern. The first noticeable loss in flavor is generally associated with the first symptoms of translucence in the tissue. It is necessary to cut through the fruit to judge condition, since fruit held under good storage conditions may appear sound from the outside while being seriously deteriorated internally. See the section on Sweet Cherries for diseases. See the section on Diseases under Peaches and Nectarines for information on cold storage and sulfur dioxide injuries.

SWEET CHERRIES

Harvesting Techniques

Sweet cherries for storage must be harvested with stems attached.

Cooling

Rapid cooling to -1°C is essential if the fruit is to be stored. Hydrocooling has been used successfully, and the wetting is tolerable as long as the fruit remains cold. Fungicidal postharvest sprays or dips are helpful in reducing decay during storage.

Forced-air or pressure cooling can be used to quickly cool the fruit without the problem of wetting. Moisture loss and stem drying can be minimized by rapid movement from the field to the cooler, rapid cooling, and maintaining low temperatures and high humidity during cooling and storage.

Storage

When sweet cherries are stored, they are normally held in shipping containers, often with polyethylene liners. These liners permit an increase in CO_2 gas surrounding the fruit, which tends to reduce decay rates and increase storage time. Cherries should be stored at -1°C and may be held 2 weeks after harvest and still retain enough quality for shipment to market.

Controlled atmospheres with 10 to 15% CO_2 and 3 to 10% O_2 help maintain firmness and bright, full color during storage. Polyethylene liners can extend the market life. The liner must be perforated when removed from storage. Modified atmosphere bags are now used commercially.

Diseases

Alternaria and Cladosporium Rot. Light brown, dry, firm decay lining skin breaks that can be removed easily from surrounding healthy tissue. Mycelium on the area are fine and white above and dark green below. *Control:* Sort out cherries with cracks and other skin breaks at packing. Use fungicide in spray or sizer on packing line.

Blue Mold Rot (*Penicillium*). Circular, flat spots covering conical, soft, mushy decay that can be scooped out cleanly from surrounding healthy flesh. White fungus tufts turning to bluish green develop on surface. Musty odor and flavor. *Control:* Prevent skin breaks. Use fungicide in spray or sizer on the packing line. Market promptly. Refrigerate promptly to 0°C .

Brown Rot (*Monilinia*). See the section on Diseases under Peaches and Nectarines. *Control:* Follow recommended orchard spray practices. Use fungicide in spray or sizer on packing line. Refrigerate promptly to 0°C . Package cherries in polyethylene bags to reduce desiccation of stem and fruit, preserve color, and reduce decay development.

Gray Mold Rot (*Botrytis*). Light brown, fairly firm, watery decay covered with extensive delicate, dirty-white mycelium. On completely decayed cherries, grayish-brown velvety spores may be found. *Control:* Handle carefully. Use fungicide in spray or sizer on packing line. Refrigerate promptly to 0°C .

Rhizopus Rot. Extensive soft, leaking decay with little change from normal color. Coarse mycelium and black spore heads are prominent under moist conditions. More prevalent in upper-layer packages in refrigerator car. *Control:* Rhizopus develops very slowly at temperatures below 10°C , so storage at recommended temperature keeps decay in check.

PEACHES AND NECTARINES

This discussion relates primarily to peaches but also applies to nectarines in many respects.

Storage Varieties

Peaches do not adapt well to prolonged storage. However, if they are sound and well matured, most freestone varieties can be stored for up to 2 weeks (some freestone and most clingstone for up to 4 weeks) without any noticeable deterioration in flavor, texture, or appearance. Storage life appears to depend on the harvest season. Early varieties, particularly the freestone peaches grown in Florida and the early clingstones grown in the Southeast, have an extremely short storage life and should be used as soon as possible after harvest. However, some late season varieties can be safely stored for up to 6 weeks. In the West, the Rio Oso Gem and several other varieties can be stored for 4 to 6 weeks before being marketed.

Harvest Techniques

Peaches for fresh consumption must be in a condition to survive a postharvest holding period of several days to several weeks. The fruit must be sound and bruise-free and must be handled delicately during the harvesting and packing operations. With the widespread use of bulk bins or pallet boxes, hand-picked fruit requires extra-careful handling. Hydrodumpers are generally used for dumping the pallet bins. With proper care, pallet boxes cause less bruising than small field boxes.

Cooling

Cooling peaches to 4°C soon after harvesting is essential to post-harvest retention of quality and control of decay. Peaches begin to soften and decay in a few hours without proper temperature management. All peaches shipped out of the Southeast are hydrocooled. Originally, the fruit was cooled in flood-type hydrocoolers as a final operation after it was packed in containers. In the West, most fresh

peaches are hydrocooled or forced-air cooled in pressure coolers before packing to remove the field heat rapidly for the postharvest holding period. Forced-air cooling is used after packing to complete the cooling process. With forced-air or pressure cooling, peaches or nectarines in two-layer plastic tray packs with 6% side-vented corrugated containers will cool 80% in about 6 h with an airflow of 0.2 L/s per kilogram of fruit.

Storage

Peaches are normally stored in corrugated or tray pack shipping containers.

An environment of -0.5°C and 90 to 95% rh with very low air movement is best for peaches. Under these conditions, peaches can be held for 2 to 6 weeks, depending on variety.

The same storage conditions may be used for nectarines; however, they are somewhat more susceptible to shrivel than are peaches. Air velocity in the storage room should be as low as possible but still maintain proper storage temperatures. Frequent checks should be made of the fruit at the edge of alleyways, for example, to detect the first signs of shrivel.

Good experimental CA results have been obtained with peaches and nectarines held in 1 to 2% O_2 with 3 to 5% CO_2 at 0°C . Extended storage of 6 to 9 weeks is possible. The fruit ripens or softens with good flavor and is juicy on removal. Low-temperature breakdown, which is usually encountered with lengthy storage, is controlled by CA. Although CA reduces decay, it does not completely control it; thus, a fungicide is needed for extended storage.

Diseases

Brown Rot (*Monolinia*). Extensive firm, brown, unbroken areas turning dark brown to black in the center and generally covered with yellowish-gray spore masses. Skin clings tightly to center of old lesions. *Control:* Follow recommended field and postharvest control measures involving use of heat treatments and fungicides. Refrigerate promptly to as near 0°C as feasible.

Cold Storage Injury. Fruit loses flavor, becomes dry and mealy. Breakdown starting around pit is grayish brown, water-soaked, or mealy. *Control:* Refrigerate promptly to 0°C . Breakdown appears earlier at 3°C . Store for only 2 to 4 weeks, depending on variety.

Pustular Spot (*Coryneum*). Common on peaches from the West, occasionally on Eastern fruit. At first small purplish-red spots, later up to 13 mm in diameter, brown, sunken with white center. *Control:* Treat with orchard sprays. Cool harvested fruit to below 7°C .

Rhizopus Rot. Extensive, fairly firm, watery decay with uniformly brown surface color. Skin slips readily from center of lesions. Coarse mycelium, black spherical sporangia develop. *Control:* Store cannery peaches at 0°C before ripening. Prevent skin breaks. Follow recommended field and postharvest control measures. Refrigerate promptly to as near 0°C as feasible.

Sulfur Dioxide Injury. Bleached and pitted areas on fruit surface. After removal from refrigeration, injured areas of peaches are brown, dry, and collapsed. Skin may slough off. *Control:* Avoid SO_2 contact of peaches (and other stone fruit) in storage or in transit with grapes.

Sour Rot. An unfamiliar postharvest disease in peaches noticed in some packing sheds in the southeastern states. First signs of the infection may be peaches that are easily skinned by the brushes and belts on the packing line. Affected peaches then develop softened and sunken brown lesions that eventually become covered with a white or creamy exudation. The infected areas generally emit a vinegar-like, sour odor. *Control:* Chlorination of dump tank water, chlorination of hydrocooling water, and careful culling of all overripe, bruised, and damaged fruit. In short, good shed sanitation and quality control are the keys to eliminating sour rot.

APRICOTS

Apricots are not stored for a prolonged time but may be held for 2 or 3 weeks if they are picked while firm enough that they will not bruise. Unfortunately, this maturity does not yield good dessert-quality fruit. Care must be used in sizing and packing the fruit going into storage, as small surface bruises can become infected with disease-producing organisms. [Chapter 10](#) has further details.

Apricots for short-term storage are harvested in much the same way as freestone peaches, precooled, and placed in storage promptly. Storage temperature should be 0°C with 90 to 95% rh.

Diseases and Deterioration

See the section on Peaches and Nectarines.

BERRIES

Blackberries, raspberries, and related berries cannot be stored for more than 2 or 3 days even at -0.5°C with a relative humidity of 90 to 95%. An atmosphere with 20 to 40% CO_2 will increase storage life by 3 or 4 days by inhibiting fungal rots.

As they come from the field, cranberries are stored in field boxes at 2 to 4°C and 90 to 95% rh. They are usually not stored longer than 2 months. Storage at -1 to 0°C causes chilling and physiological breakdown. Modified atmospheres have not extended the storage life of fresh cranberries beyond that attainable in conventional storage.

Diseases

Cladosporium Rot. Surfaces of berries covered with olive to olive-green mold. In raspberries, the mold is most abundant on inside or cup of berry. *Control:* Avoid bruising; pack and ship promptly. Refrigerate to 0°C .

Gray Mold Rot. Causes soft, watery rot. Fruit may be covered with dense, dusty gray growth of fungus, which spreads rapidly in package, forming nests. *Control:* Avoid bruising. Refrigerate to 0°C in transit and use modified atmosphere packaging (MAP).

Anthracnose (*Gloeosporium* sp.). Berries may be completely rotted and show masses of spores glistening in salmon-colored droplets on fruit. *Control:* Refrigerate to 0°C .

Alternaria Rot. Affected berries remain firm and show gray-white woolly fungal growth from injured cap-stem areas. Nesting occurs in tight clusters scattered throughout containers. *Control:* Refrigerate to 0°C .

Chilling Injury. Berries held for 4 or more weeks become tough and rubbery; surfaces are dull in appearance, red in color throughout. *Control:* Hold fruit at 2.8°C .

Fungus Rots (Several Fungi). Limited portions or entire berries are brown, soft, or collapsed. Some berries turn into water bags. *Control:* Spray in field. Handle carefully. Reduce temperature to 3.3°C after harvest.

STRAWBERRIES

Diseases

Gray Mold Rot (*Botrytis*). Brown, fairly firm, fairly dry decay. Dirty-gray mold and grayish-brown velvety spore masses present. Nesting common. *Control:* Apply recommended fungicides in field. Handle carefully to prevent skin breaks. Cull out all diseased berries. Cool promptly to 4°C or below.

Leather Rot (*Phytophthora*). Large, slightly discolored tough areas with indefinite purplish margins. Vascular system browned, flavor bitter. *Control:* Mulch plants to keep berries from contact with infested soil. Cool promptly to 4°C or below.

Rhizoctonia Rot. Hard dark brown decay on one side of berry, usually small quantities of soil adhering. Develops only a little after

harvest. *Control*: Mulch plants to keep berries from contact with infested soil. Cull thoroughly.

Rhizopus Rot. Mushy, leaky collapse of berries associated with coarse black mycelium and sporangia. Extensive red staining of containers from leaking juice. *Control*: Reduce temperature promptly to 4°C or below. Handle carefully to prevent skin breaks.

FIGS

Diseases

Alternaria Spot. White fungal growth on surfaces that soon darkens. As fungus spots enlarge, tissue beneath becomes slightly sunken. *Control*: Cool promptly after harvest, hold at 7°C in transit.

Black Mold Rot (*Aspergillus*). Disease first appears as a dirty-white to pink color of the skin and pulp. White mold growth develops within fig. Cavities formed in fruit become lined with black spore masses. *Control*: Store fresh figs at 0°C and 85 to 90% rh.

SUPPLEMENTS TO REFRIGERATION

Antiseptic Washes

Many types of fruit are washed before packing to remove dirt and improve appearance. In some cases, hydrocoolers are used to remove field heat. If the water is recirculated, it may become heavily contaminated with decay-producing bacteria and fungi. Chlorine can be added to the water at 50 to 100 mg/kg to control the buildup of these organisms. Other fungicides may also be used, but they must be legally registered for the specific application.

Protective Packaging

Proper packaging protects against bruising, moisture loss, and spread of disease. Packaging materials may also contain chemicals to control spoilage. Packages must have good stacking strength for palletizing and must also perform under high humidity.

Selective Marketing

The potential storage life of grapes and apples can be predicted within a few weeks after they are stored. Thus, those with a short storage life may be marketed while still in good condition, and longer lived products can be stored for late-season marketing. Samples taken from each lot placed in storage are kept for a few weeks at temperatures and relative humidities that favor rapid development of decay. Grapes that will not keep long can be detected in about 2 weeks and apples in about 60 days. Since both kinds of fruit may be stored for several months, knowing their potential storage life can significantly reduce spoilage losses.

Heat Treatment

Heat treatments to reduce decay also kill insects on and microorganisms near the surface of the fruit without leaving a residue. For example, brown rot and rhizopus rot of peaches are reduced by exposing the fruit for 1.5 min in 55°C water or for 3 min in 49°C water.

Fungicides

Fungicides may be applied during cleaning, brushing, or waxing of some fruit. Only fungicides registered for the particular fruit and application may be used.

Irradiation

Gamma radiation has effectively controlled decay in some products. High dosages can cause discoloration, softening, or flavor loss. Commercial application of gamma radiation is limited due to the cost and size of equipment needed for the treatment and to uncertainty about the acceptability of irradiated foods to the consumer (Hardenburg et al. 1986).

Ultraviolet lamps are sometimes used to control bacteria and mold in refrigerated storage. Although ultraviolet light kills bacteria and fungi that are sufficiently exposed to the direct rays, it does not reduce decay of packaged fruit in storage. Even ultraviolet light directed on fruit as it passed over a grader did not control decay.

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