

# Postharvest Handling Practices and Postharvest Diseases of Fruit

Disease or threat of disease dictates in large measure the manner in which perishable fruits are handled. Early fruit shippers minimized fruit disease, despite the absence of fungicides, by careful sorting, temperature management, expeditious handling and transportation, and assurance of proper fruit maturity. Modern handlers minimize disease pressures by the same methods to often greatly improve the effectiveness of chemical treatments.

Handling methodology was developed largely by trial and error during the latter part of the last century and early years of the present by shippers brash enough to take large risks in shipping highly perishable commodities long distances to new and attractive markets. Probably in few places in the world have these measures been so widely adopted and continually improved upon as on the west coast of North America.

Gringo settlers arriving in California marveled at the figs, grapes, peaches, apricots, and other fruits growing in mission gardens. The excellence of the environment for fruit growing was recognized, and these settlers longed to ship fruits to eastern markets in the United States. An early recorded attempt was a test shipment without refrigeration of mission grapes from Pleasant Valley, near present-day Sacramento, to Philadelphia. Packed in sawdust-filled casks, the grapes were transported to San Francisco by horse-drawn wagon, which presumably required 2 or 3 days. In San Francisco, the cargo was placed on a clipper ship bound for Panama. After transshipment across the isthmus, the cargo was placed aboard another clipper ship for Philadelphia. The attempt failed.

The coming of the railroad stimulated

further attempts to ship fruit transcontinentally, which met with a measure of success. Dependable transportation came with the development of special cars equipped with bunkers to provide refrigeration from melting ice. Fortunately, ice for the cars could be harvested from mountain lakes during the winter and stored for the summer shipping season. The development of ice-making machinery permitted icing stations to be located at intervals along the railroad. In the 1960s, refrigeration from melting ice was largely replaced by mechanical units in American railroad cars or truck reefers. Air transport provides speed in lieu of good temperature management, but refrigeration is generally required during ground handling at shipping and receiving points.

In recent decades, fruits have increasingly been shipped to even greater distances from points of production. Exploitation of these distant markets, however, may offer large economic benefits only if the life of the commodity is stretched to its limit. Diseases and disorders ordinarily manageable during handling and transcontinental transit and marketing may be excessive when transoceanic marine transport of longer duration is involved. Similarly, the extension of marketing periods by storing fruits until they near the end of their physiological life may pose additional disease problems. Losses are especially serious if they occur in market areas because they include costs of sorting, packaging, cooling, storage, and transportation, which may exceed production costs by far. Of even greater long-term importance may be an impaired reputation leading to reduced future sales (11).

The purpose of this discussion is to relate modern fruit-handling practices to the potential for disease losses after

harvest. In some cases, relationships have been well researched. In others, observed cause-effect connections must be largely inferred.

## Nature of Postharvest Diseases

Postharvest diseases are often extensions of disease occurring in the field or orchard (Fig. 1). Brown rot of stone fruits (*Monilinia fructicola* (Wint.) Honey), for example, may cause blossom and twig blighting in the orchard. Infections in the orchard may not be visible at harvest but develop quickly after harvest if fruits are not refrigerated. *Colletotrichum gloeosporioides* (Penz.) Arx may attack blossoms or leaves and young fruit of citrus, avocados, mangos, papayas, and a wide range of other tropical and subtropical species; infections in developing fruit are usually latent, and rot lesions appear only at the onset of fruit ripening. *Pezizula malicorticis* (Jacks.) Nannfld. causes cankers of limbs of apples and pears; infections in developing fruit are latent, and active rotting usually commences only after the fruit has spent several months in storage and proceeds during  $-1^{\circ}\text{C}$  storage because the organism is able to grow at very low temperatures. These fungi used as examples are able to produce appressoria and to penetrate the cuticle and epidermis of the fruit.

Whether capable of being penetrated directly or not, wounds are often the usual means by which the fungus enters fruit. Cuts, punctures, bruises, and abrasions cannot be avoided completely during harvest and handling. If the cuticle and epidermis are broken, spores find nutrients and humidity in fresh wounds ideal for spore germination and colonization (Fig. 2). Separation of fruits from the parent plant at harvest creates an unavoidable wound that encourages stem-end rots (Fig. 3).



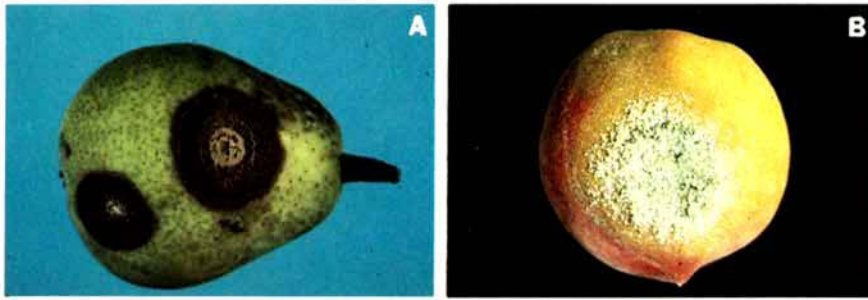


Fig. 1. Pathogens in the orchard may attack developing fruit but infections remain latent or quiescent until after harvest. (A) Bull's-eye rot (*Pezizula mallicorticis*) appears in pears and apples after months in refrigerated storage. (B) Peaches and other stone fruits become susceptible to brown rot (*Monilinia fructicola*) at harvest.



Fig. 2. Fingernails or other sharp, spore-contaminated objects cause wounds that are readily colonized, as in this nectarine infected by *Monilinia fructicola*.

Rots developing at the blossom end usually involve prior colonization of floral parts. For example, *Botrytis* blossom-end rot (*B. cinerea*) sometimes occurs in Bartlett pears after a month or two in storage at  $-1\text{ C}$  (Fig. 4). Initiation of rot in fruit flesh is associated with old styles and stamens retained within the fruit. Floral infections occur in the senescing floral parts at the end of blossoming. Mostly these floral parts are invaded by *Alternaria* spp. and common saprophytic fungi, but *B. cinerea* is found occasionally also. Not all fruits having *B. cinerea*-invaded floral parts rot in storage, but a significant percentage do. By contrast, test fruits remain free from *Botrytis* blossom-end rot if the old floral parts of developing fruits are free from *B. cinerea*. Rotting of fruits in storage is greatly reduced by a single orchard spray at the end of blossoming.

Contact infection, by which mycelia grow from a rotting fruit to contact and penetrate nearby fruit (Fig. 5), is an especially serious feature of some very common postharvest pathogens. The ever-enlarging "nest" of rotting fruit tied together by fungus mycelia will involve all fruit in a container, if given sufficient time.

### Physiology of the Fruit in Relation to Disease

Sugars translocated from photosynthesizing leaves to developing fruits provide chemical energy and carbon

building blocks. Within living cells of fruits, metabolic processes convert sugars (along with minerals and water from the soil) into the myriad of compounds that comprise the living cell and its storage reserves. These metabolic reactions require chemical energy obtained from compounds in the cell by respiration, a process which itself requires energy to function.

Respiration is thus a process by which captured energy of light stored in organic compounds by photosynthesis is released by oxidation (low-temperature burning). Respiration is not entirely efficient, because not all resulting energy is usable chemical energy. Some is wasted and given off as heat, the so-called "heat of respiration" or "vital heat."

While a fruit is still attached to the tree, the substances oxidized to  $\text{CO}_2$  and  $\text{H}_2\text{O}$  are easily replaced by photosynthates from green leaves or storage reserves in stems. But once the fruit is separated from the tree, it is on its own. The respiration process must continue functioning to produce energy for cellular functions or the tissues die. The only available fuel is that stored within the fruit itself.

Since  $\text{O}_2$  is consumed and  $\text{CO}_2$  is lost during respiratory oxidation, measurements of either can be used as an index of respiration. Analyses of these gases indicate the "rate of living." Perhaps it more properly should be called the "rate of dying," because the fruit tends to consume itself as a consequence of respiration.

In a large measure, postharvest environments are designed to reduce the rate of respiration to the minimum required to maintain vital processes. By so doing, the stored reserves are conserved, the onset of ripening is delayed, and the normal resistance of the fruit to postharvest disease is maintained longer.

On a dry-weight basis, small fruits soon after blossoming have extremely rapid respiratory rates (9), which then decline through fruit development and maturation (Fig. 6A). Often, however, respiration will increase sharply, starting shortly before fruits ripen, senesce, and die (Fig. 6B). This frenzy of metabolic activity,

called the climacteric rise in respiration, generally peaks when the fruit is ripe enough for eating. Climacteric fruits include apple, apricot, avocado, banana, cherimoya, mango, papaya, peach, pear, plum, and tomato (17,18).

During the climacteric rise, fruits commonly soften and yellow colors intensify through loss of chlorophyll and increase of carotenoid pigments. Xanthophylls (red, blue, and purple colors) may be produced. Ethylene ( $\text{C}_2\text{H}_4$ ) is detected at the start of the climacteric respiratory rise, and its evolution increases along with volatiles associated with fruit aromas. The significance of the climacteric rise has long been debated inconclusively. The climacteric rise is a convenient reference point in indicating the physiology of the commodity after harvest. It is of pathological interest because the climacteric rise coincides with a dramatic change in fruit resistance to certain postharvest pathogens.

In fruits that do not have a climacteric increase in respiration, the rate of respiration decreases gradually after harvest. They exhibit certain color changes associated with ripening and soften, but it is difficult to pinpoint when ripening begins. Certain fruits—citrus, for example—may degreen apparently in response to maturation or ripening, but they will subsequently regreen under certain environmental conditions. Such nonclimacteric fruit as cherry, citrus (all), fig, grape, pineapple, and strawberry (17,18) do not have large reserves of starch or oils on which to draw for vital processes. Fruit taste may be sweeter if acids are destroyed, but large increases in sugars do not occur after harvest.

Obtaining the maximum postharvest life in fruits depends on maintaining the fruit in a highly vigorous condition by lowering the respiration rate to the minimum at which the fruit will retain normal cellular function. Climacteric fruits should be harvested before the rise in respiration, and temperatures should be lowered to dramatically suppress and delay the peak of respiration (Fig. 6C). Further, suppression may result from use of modified atmospheres (19).

### Wound Healing

Fungal spores often infect fruit by invading cuts, punctures, or tears in the fruit skin inflicted during harvest or handling. Fresh wounds that escape colonization by fungi often become less subject to subsequent colonization. In particular, wounds in fruits removed from lengthy refrigerated storage may no longer be highly prone to fungal invasion. It is not a matter of callus formation and periderm differentiation, because fruits have long since lost their ability to heal wounds in this manner by harvest time. Some reduced susceptibility of wounds might be explained by drying of the



wound area. However, one can judge that biochemical wound healing is likely very important despite a paucity of studies with fruits (13).

When fruits are cut or otherwise damaged mechanically, they start respiring more rapidly, as measured by oxygen consumption or carbon dioxide evolution, and ethylene is usually readily found. In plant tissues in which the effects of cuts have been studied in detail, several events have been noted (13). Cells ruptured by the cut are killed, and the cellular contents are mixed and exposed in the wound area. Browning in the wound results from enzymatic oxidation of phenolic compounds. Living cells near the injury are stimulated to become very active metabolically, even though they themselves do not show signs of major injury. Repair is set in motion by these stressed but unbroken cells. Polyphenol synthesis may lead to the accumulation of greater quantities of those already present. New compounds, which may play a special role in defense, may appear in the wound or in response to infection (14). Such substances may also be polyphenols. Some of the compounds produced as a result of wounding are highly toxic to fungi. Germinating spores that may be deposited in such "protected" wounds are presumably killed or suppressed.

### Maturity

Fruits are generally harvested before they are completely ripe in order to secure sufficient time for long-distance transportation and marketing. Harvesting well before ripening begins ensures that fruits will have a higher resistance to certain diseases than will fruits harvested later. Further, preclimacteric fruits are usually firmer and less subject to mechanical injury from handling than fruits harvested after the onset of ripening.

As fruits approach maturity, an array of changes occur before ripening begins. Often most obvious is the change from green to yellow through loss of chlorophyll and synthesis of anthocyanin pigments; changes in xanthophyll pigments in the fruit epidermis is an index for harvesting sweet cherries and strawberries. Adequate sugar content at harvest has an important effect on quality after ripening for many fruits and can easily be estimated by use of a refractometer to measure soluble solids in extracted juice. Fruits soften as they approach maturity, and resistance of the flesh to a penetrometer is a convenient measurement. Other changes are important indices with certain fruits. For example, fruit shape is a commonly used index for bananas, starch content for apples or other fruits, and oil content for some avocados. Days from full bloom have been used as an index for apples, usually in combination with other

indices. Abscission zones forming in fruit stems are associated with maturity and are used to indicate when to harvest certain melons.

The effect of maturity or ripeness on the resistance of the fruit to postharvest pathogens has long been recognized by growers and shippers. Perhaps the most striking effects can be seen with the anthracnose organisms. Spores germinate and appressoria are produced on developing fruits in the orchard; infections are latent, and lesions do not start to develop until ripening begins. Similarly, Sitterly and Shay (19) showed that immature apple fruits were not colonized by *Botryosphaeria ribis* Gross. & Dug., *Glomerella cingulata* (Ston.) Spauld. & Schrenk, *P. malicorticis*, or *Physalospora obtusa* (Schw.) Ck., but the fruits became very susceptible as they approached maturity. In the early ripening apple cultivar Yellow Transparent, *B. ribis* and *G. cingulata* produced lesions only after the start of the climacteric respiratory rise; *P. malicorticis* lesions developed a week later.

Drops of conidial suspensions of *Colletotrichum musae* (Berk. & Curt.) Arx placed on the skin of mature but still green Cavendish banana fruits incited germination-inhibiting substances in tissues below (3). Antifungal activity was detected after 2 days and reached a maximum after 7 days. Thin-layer chromatography separated the antifungal activity into five spots. Germination suppression could not be detected in ripe fruits. Normal progressive lesions developed only after onset of the climacteric rise in the respiration rate.

Resistance in apples to *Nectria galligena* Bres. was shown to result from the formation of benzoic acid in fruit tissue as a response to infection (20).

The time at which apparently unstressed fruits become susceptible to postharvest pathogens depends greatly on the pathogen as well as on the host. Some show susceptibility when puncture-inoculated long before ripening begins, even though natural rotting generally occurs after harvest. By contrast, susceptibility of unstressed Bartlett pears to *Phoma* spp. and *Alternaria alternata* and, to a lesser extent, *B. cinerea* in storage has been associated with advanced senescence.

### Temperature

Temperature management is so critical for controlling postharvest disease that all other control methods are sometimes described as "supplements" to refrigeration. Without intending to minimize the importance of other handling measures, one can say without a doubt that temperature management is central to modern postharvest handling systems, because not only do low temperatures slow fungus development but the lowest temperature tolerated by the commodity maximizes its physiological postharvest life.

Despite its overwhelming importance, temperature management is probably the fruit-handling practice most often poorly done. Frequently, facilities are inadequate or the problems of temperature management are poorly understood by handlers. In reality, temperature involves two processes having different require-

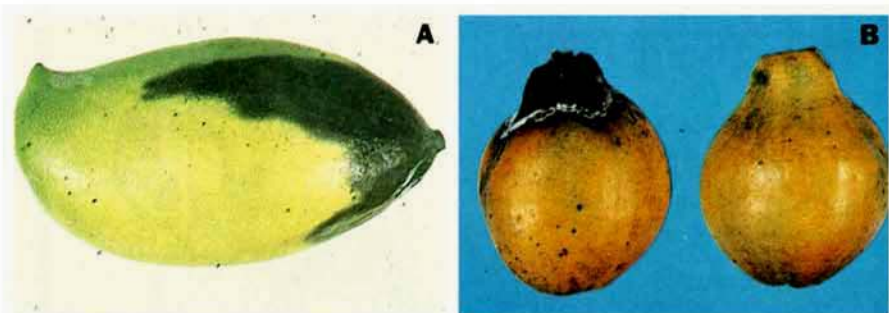


Fig. 3. Invasion of stems: (A) *Diploidi natalensis* rot of mango and (B) *Ascochyta carlicae* rot of papaya.



Fig. 4. *Botrytis cinerea* in retained styles and stamens invades flesh of Bartlett pears after 1 or 2 months of storage at  $-1^{\circ}\text{C}$ .



ments. The first is "cooling," or removing field heat and lowering the temperature of the fruit to its storage temperature. Rapid cooling requires a high refrigeration capacity and the ability to move the cooling medium around or near individual fruits. The second step is maintaining the low temperature by removing the heat of respiration and heat which leaks into insulated storages or transit vehicles. This normally requires only a fraction of the refrigeration capacity required for cooling, and air movement should be modest to minimize moisture loss from the commodity.

Ideally, cooling is accomplished by cold air (forced-air cooling) or cold water (hydrocooling). Commodities with the least urgency for prompt removal of field heat may be cooled satisfactorily in storage rooms with sufficient refrigeration capacity and adequate air movement (15). Refrigerated vans or marine containers are ordinarily unsatisfactory for cooling because they are designed to transport frozen foods where the sole requirement of refrigeration is to remove heat leakage into the container. The refrigeration and air movement capacities are usually inadequate to permit the satisfactory removal of field heat.

Commodities having the greatest urgency for prompt and rapid cooling include strawberries and other berries

and cherries. Field heat should be removed within several hours of harvest. Of intermediate urgency are peaches, nectarines, plums, grapes, papayas, guavas, mangos, and pineapples. Less urgency is required for most cultivars of apples, pears, citrus, and bananas. Disease pressures or extra-perishable cultivars may increase the urgency for prompt cooling.

**Temperature requirements of post-harvest pathogens.** The effects of temperatures on growth of postharvest pathogens are illustrated by *M. fructicola* growing in peach fruits (Fig. 7A). Postharvest rot fungi generally grow best at about 20–25 C, depending on the fungus species; a few grow best at slightly higher temperatures (5,7). The maximum temperatures at which fungi can grow are typically about 27–32 C, but some species can grow at higher temperatures.

Fungi can be conveniently divided into those that have a minimum temperature for growth of about 0 C or above and those that can grow at lower temperatures. Fungi that can grow at temperatures as low as –5 to –2 C cannot be completely stopped by refrigeration without freezing the fruit. Some people mistakenly believe, therefore, that keeping temperatures low to control these fungi is unimportant. Nothing could be further from the truth. Although the fungi are

active, their growth rate is only a minute fraction of the rate at which they grow when temperatures are higher. Figure 7B shows the extent of rot development in peaches after inoculation with spores of *M. fructicola* and holding at 2.5, 5, 15, and 25 C.

**Significance of the sigmoid growth curve.** The development of lesions by fungi can be illustrated by means of the sigmoid curve and terminology commonly used to describe bacterial growth (Fig. 8A). When a fungus spore is on a medium suitable for growth (such as a fresh wound in a fruit), the spores swell, and after a few hours the germ tubes protrude and lesions begin to form. The time taken to germinate and start lesions can be called the "lag phase." Growth and lesion development soon achieve a rapid steady state, called the "log phase." Although the log phase may describe truly logarithmic growth in bacteria and other single-celled organisms, sustained logarithmic growth cannot occur in filamentous fungi, in which only a fraction of the "cells" are dividing at any time. Eventually, growth slows for some reason and the "stationary" phase begins.

The lag phase is usually longer in fruit than on culture medium because the spore not only must germinate but also must initiate growth in the living tissues of the fruit despite resistance of the tissues. Again, partially because of fruit resistance, the rate of growth in the log phase may be slower than that in culture. The rate of growth slows when much of the fruit has been invaded.

As the temperature is lowered from near optimum to less favorable, growth curves change considerably but retain the general sigmoid shape. A striking feature of the curve is that time involved in the lag phase becomes greatly extended as a consequence of very slow germination and establishment of the infection. Depending on the fungus species, the lag phase may lengthen from a few hours to several days at optimum temperatures to weeks or months at temperatures near minimum for fungus growth. Even when a steady state has been reached, the very slow growth rate results in a much reduced slope of the log phase. This effect is illustrated by the development of brown rot in peaches. The length of the lag phase can be seen by extending the lower point of each curve to zero days (Fig. 7B).

Figure 8B illustrates the importance of the lag phase in fruit handling. Data show the amount of brown rot that developed in peaches following delays in fruit cooling. After inoculation with spores of the fungus, one group of fruit was placed immediately at 0 C, whereas others were placed at that temperature after being held for 24 and 36 hours at 20 C. After 3 days at low temperatures, obvious disease lesions had not developed. Data taken after the third and sixth days at 15 C show



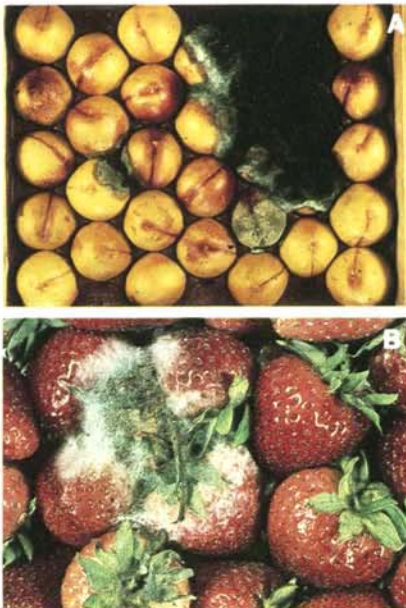


Fig. 5. Mycelial infection and "nesting" of packed fruits: (A) *Rhizopus* sp. (black) and *Monilinia fructicola* (gray-tan) in nectarines and (B) *Botrytis cinerea* in strawberries.

that the effects of delayed cooling extend into the normal marketing period.

A high percentage of spore-contaminated wounds may not develop into lesions if cooling is sufficiently prompt. Spore germination is extremely slow and may fail near the minimum temperature for growth of the fungus. Processes involved in establishing the infection are also likely to be marginally functional near growth-stopping temperatures. Consequently, temperatures that are low while the fungus is still early in the lag phase may result in fewer fungal lesions and delay their development in the fruit.

**Fungal sensitivity to cold.** Some postharvest pathogens having minimum temperatures for growth of about 5°C or higher have developmental stages very sensitive to low temperatures. *Rhizopus stolonifer* and *Aspergillus niger* are examples. Although the ungerminated spores are not affected adversely by low temperatures of fruit storages, most spores that have started to germinate may be killed by several days at 0°C. Generally, young mycelia in very small lesions in the fruit are sensitive to cold but fungus inactivation in larger lesions will not be total.

**Chilling sensitivity.** Some fruit species or cultivars are injured at temperatures well above freezing. The phenomenon, called chilling injury, is most common among tropical and subtropical species but certain cultivars of apples and other temperate-zone fruits may also be affected. Symptoms vary with the cultivar, and severity increases with decreasing temperature or length of exposure to the chilling temperature. Loss of resistance to fungal pathogens occurs before such visible host symptoms

as skin pitting, browning, or water-soaked tissues appear. Papaya fruits, for example, are chilled by extended periods much below 15°C (Fig. 9A). Unchilled fruits are highly resistant to *Alternaria* spp. but become highly susceptible when exposed to cold even if no host injury is visible. A similar loss of resistance to *Alternaria* spp. occurs when California-grown Yellow Newtown apples are stored at < 3°C for extended periods (Fig. 9B). Chilled tomato and cucumber fruits are rotted by *Alternaria* spp. and *Fusarium* spp.

### Humidity

Problems of accurately measuring relative humidity (RH) in the microclimate of the surface of fruits and large changes in RH due to minor temperature fluctuations have made studies of humidity effects difficult under postharvest conditions. With pathogens such as *M. fructicola*, germination and direct penetration of stone fruits are aided by saturated atmospheres that usually result in condensation on the fruit surface when temperatures cycle in refrigerated rooms. Such high humidities are not usually encountered in refrigerated storage or transit. With jacketed storages or packages with moisture barriers of plastic film, the high humidity might be a factor in promoting disease if temperatures were favorable. The disease-enhancing tendency of these high-humidity environments would likely increase if fruits were wet when packaged.

Cold fruits removed from refrigerated to ambient temperatures condense moisture on their surface from surrounding warm humid air. This sweating continues until the temperature of the fruit has warmed to near ambient. The duration of the sweat depends on such factors as the fruit-air temperature difference, the exposure of the fruit to the air, air movement, and fruit size. Although moisture from "sweating" at the fruit surface has often been a concern among handlers, it appears likely that the warm-up period is usually too short to be an important factor.

The horticultural necessity for maintaining high humidity in fruit environments is primarily to minimize loss of moisture, which results in shrivel and loss of turgidity. With peaches, for example, a loss of 3-4% of the original weight usually results in noticeable shrivel. The effect, if any, of weight loss on disease resistance requires added studies. In some vegetables, however, weight loss has been associated with increased susceptibility to disease. Carrots in storage were initially resistant to *B. cinerea* but became susceptible after a moisture loss of 8% (10).

### Ethylene

The ripening of many fruits can be dramatically hastened by exposure to

ethylene. Bananas, for example, are shipped while green and still resistant to most fruit diseases. They are purposely exposed to ethylene in market areas to obtain rapid and uniform ripening. Such carefully controlled ripening can limit disease by reducing the time between loss of resistance and consumption, but inadvertent exposure of fruits to ethylene can result in unexpected early ripening and subsequent large losses to disease.

Ethylene in exhausts of internal combustion engines of forklift trucks or other vehicles is a common cause of untimely ripening. Sometimes fruit is the source of ethylene. As fruits begin to ripen, ethylene is evolved. If a few ripening fruits are present, the evolved ethylene may trigger ripening of the bulk of the fruit of normal (preclimacteric) maturity. Similarly, the ethylene from wounded fruits may be sufficient to trigger ripening of the unwounded. A large amount of ethylene is evolved from rotting fruits. Many pathogens produce ethylene but the bulk of the ethylene probably arises from the attacked host tissues. This evolution of ethylene by rotting fruit is surely the basis of the adage "one bad apple spoils the barrel."

It appears that ethylene's effect on ripening is not the only way it affects fruit

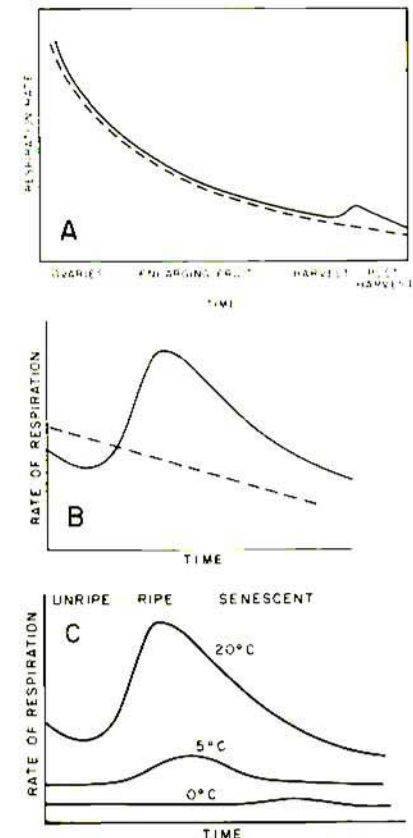


Fig. 6. Respiration patterns of fruits as measured by  $CO_2$  evolution. Rates of climacteric (solid line) and nonclimacteric (broken line) fruit (A) throughout life and (B) after harvest. (C) Suppression and delay of the climacteric respiratory rise by low temperatures.



resistance. More complex, not yet well-understood roles are suggested by recent studies in which ethylene seemed to enhance resistance. For example, excessive losses from *G. cingulata* occur

when Robinson tangerine fruits are exposed to ethylene in humid "degreening" rooms. Brown and Barmore (4) exposed fruits to ethylene 3 days before harvest and observed less subsequent rotting.

## Modified or Controlled Atmospheres

Sometimes fruits are kept in atmospheres low in oxygen, high in carbon dioxide, or both. If these gases are closely controlled, the synthetic atmosphere is commonly called a controlled atmosphere. Modified atmosphere may designate any synthetic atmosphere but often means there is little or no possibility of adjusting gas composition during storage or transportation. These atmospheres are intended to extend fruit postharvest life by suppressing the rate of respiration. An alternative objective is to suppress disease.

The effects of modified atmospheres on postharvest diseases can be direct or indirect. The maintenance of the fruit in good physiological condition may result in retention of considerable disease resistance, and lowering oxygen or increasing carbon dioxide can suppress growth of the fungus.

**Low oxygen.** Oxygen is required for normal respiration of both the fruit and its fungus pathogen. The beneficial effects of low oxygen on fruit seldom become evident until oxygen in the atmosphere is decreased to 5% or below; benefits are increased at lower oxygen levels (8). In controlled-atmosphere storages, the level of oxygen is commonly maintained at about 2–2.5%. It is generally believed these levels are the lowest that can be maintained prudently with atmosphere control methods usually available in storages.

Anaerobic or fermentative respiration is caused by an excessively low oxygen level. As substances, particularly alcohols and aldehydes, accumulate in the tissues, the fruit develops off-flavors. Eventually, tissues will be irreparably damaged and the fruit will die.

Growth of *B. cinerea* in a 2% oxygen atmosphere is only about 15% below the growth in air (21% oxygen). Growth is reduced greatly if oxygen is lowered to 1%, but that is generally considered too low for product safety (6).

**Hypobaric atmospheres.** In recent years, storage and transport under low-oxygen or hypobaric (hypo = less than; baric = barometric pressure) atmospheres has stirred considerable interest. Test vans have been constructed that maintain low pressure by use of vacuum pumps and regulated flow of air through the van. Refrigeration is conventional. When a pressure is reduced to 100 or 50 mm Hg, the amount of available oxygen has been lowered from 21% at atmospheric pressure to about 2.8 and 1.4%, respectively, and growth is suppressed (Fig. 10). Very little critical data are available, but a comparison of results with *B. cinerea* at 100 and 50 mm Hg suggests that the suppressive effect is similar to controlled atmospheres at equivalent oxygen (1,6). An added

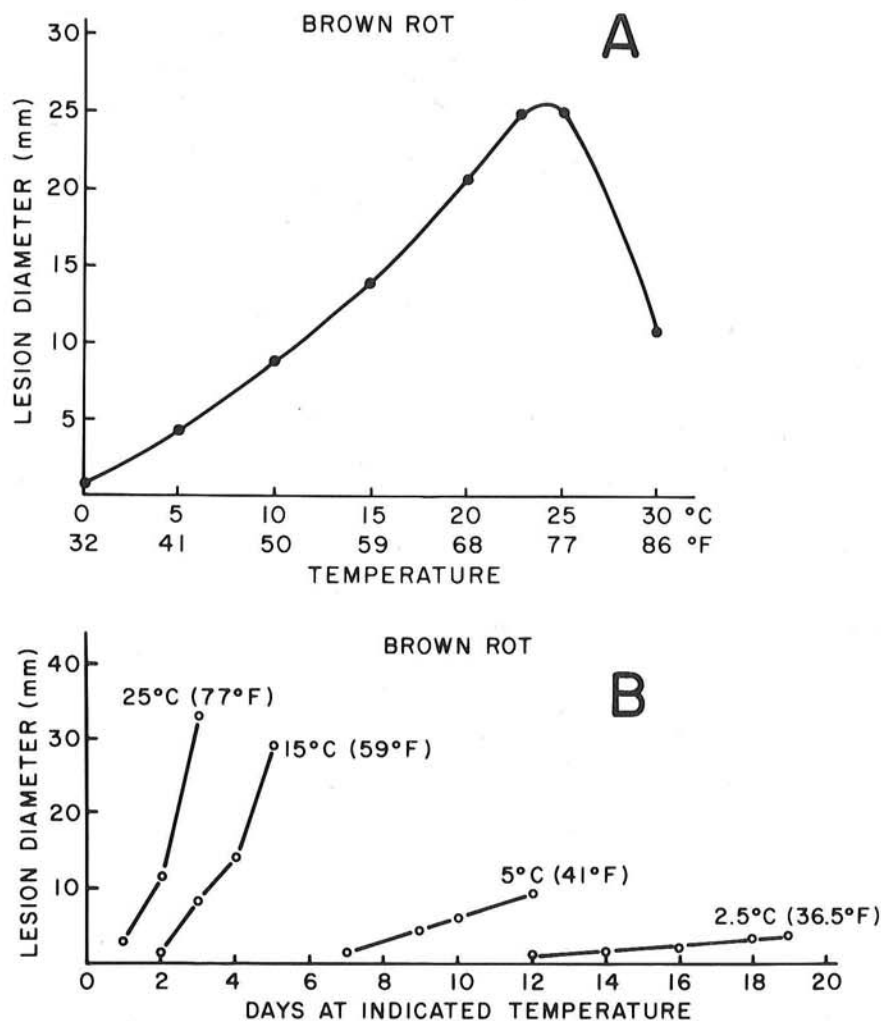


Fig. 7. Temperature effects on developing rot lesions of *Monilinia fructicola* in peach fruits: (A) Temperature response curve and (B) lesion enlargement at constant temperatures showing the extended "lag period" at low temperatures. (Brooks and Cooley [2])



Noel F. Sommer

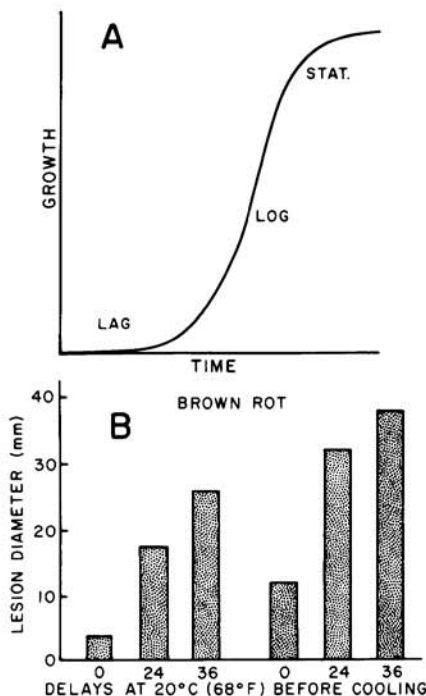
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benefit of the hypobaric storage, however, is that ethylene from tissues is swept out of the van.

**Carbon dioxide elevation.** Air commonly contains about 0.03% carbon dioxide. Elevation of carbon dioxide above about 5% noticeably suppresses fruit respiration. If the concentration of carbon dioxide is excessive, however, off-flavors develop and the fruit is injured. The relationship of carbon dioxide concentration to fruit injury is time-temperature related. Fruits tolerate very high levels of carbon dioxide (20%) for several days at transit temperatures (3–5 C), but few fruits tolerate those elevated concentrations if storage or transit in the modified atmosphere is extended for several weeks. Species and varietal differences in carbon-dioxide tolerance may be important, however.

The addition of 10–20% carbon dioxide at a transit temperature has commonly affected both host and pathogens in a manner roughly comparable to a temperature of 0 C in air. Carbon dioxide added to air has been widely used in transport of Bing cherries, primarily to suppress *B. cinerea* (gray mold) and *M. fructicola* (brown rot), and of strawberries, to suppress *B. cinerea*.

Although fungi are suppressed by high (> 5%) carbon dioxide levels, many fungi grow poorly in its complete absence. A number of enzymes have been implicated in carbon dioxide fixation within fungal cells.



**Fig. 8. Importance of cooling fruit while fungi contaminating wounds are in initial development stage (lag phase): (A) Sigmoidal nature of lesion development curve. (B) Peaches needle-inoculated with *Monilinia fructicola*, then cooled to 0 C immediately or after 24 or 36 hours at 20 C; relative rot 3 days (left) and 6 days (right) after removal from 3 days of storage.**



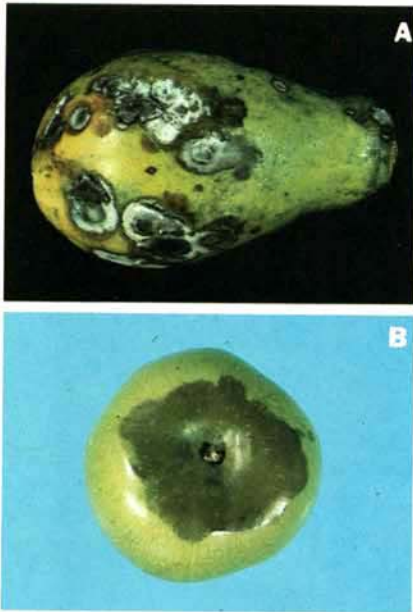


Fig. 9. Loss of resistance to *Alternaria* spp. by exposure to chilling temperatures: (A) Papaya stored for 2 weeks at 5 C and (B) Yellow Newtown apple stored at <3 C for 11 months.

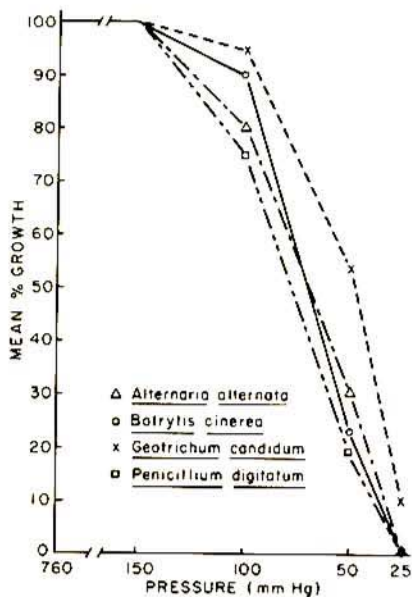


Fig. 10. Effect of low pressures on fungal growth. Pressures of 100 and 50 mm Hg result in oxygen availability corresponding to about 2.8 and 1.4%, respectively, in atmosphere at normal pressure. (Apelbaum and Barkai-Golan [1])

**Combined low oxygen, high carbon dioxide.** The effects of low-oxygen, high-carbon-dioxide atmospheres are believed to be additive. Commonly used atmospheres of about 2–3% oxygen and 5–7% carbon dioxide suppress fruit respiration rate that could not be achieved safely by modifying single gases. Modification by oxygen alone would likely require 1% or less oxygen to suppress fruit respiration similarly. Carbon dioxide in air might require 15–20% or more to equal the combined effect.

**Controlled atmosphere with carbon monoxide.** The very modest suppression of fungi by the commonly used low-oxygen, high-carbon-dioxide concentrations suggests that inclusion of a fungistatic gas would be useful. Currently, there is interest in carbon monoxide for that role (8,12,16). Although tests have been encouraging, the commercial use of carbon monoxide is still experimental.

Carbon monoxide functions physiologically as an enzyme inhibitor and as a competitor of oxygen. Carbon monoxide (10%) added to air reduced growth of postharvest pathogens only modestly. When added to an atmosphere of low oxygen (2–2.5%), however, suppression was greater. If added to a controlled atmosphere (2.2% oxygen, 5% carbon dioxide), suppression was even greater because of the additive effects of carbon monoxide and carbon dioxide.

In general, the suppressive effects of carbon monoxide increased as levels of oxygen decreased. Further, suppression is greater at 5.5 C than at 12.5 C.

### Summing Up

Postharvest handling methods leading to the maximum physiological life of a commodity are often those that minimize fungal rots. Maintaining a fruit at high vitality enhances its natural disease resistance and ability to heal wounds. Several measures for minimizing postharvest diseases are important and should be followed as much as possible:

1. Harvest fruits at optimum maturity, as determined experimentally or by experience.
2. Avoid cuts or punctures of the fruit skin, which provide an entrance for pathogens. Wounds also stimulate respiration and ethylene evolution, which may trigger ripening.
3. Cool fruit promptly to ensure high fruit vitality and natural disease resistance throughout the postharvest period.
4. Use the lowest temperature that will not damage the fruit.
5. Use controlled or modified atmospheres if tolerated by the commodity and if transport and marketing periods approach maximum postharvest life.

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