Reviews

Chlorination and Postharvest Disease Control

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Summary. **A significant portion of harvested produce never reaches the consumer due to, postharvest diseases. Various chemicals have been used to reduce the incidence of postharvest diseases. Many of these materials have been removed from the market in recent years due to economic, environmental, or health concerns. Although somewhat limited in the range of diseases controlled, chlorination is effective when combined with proper postharvest handling practices. Additionally, it is a relatively inexpensive postharvest disease control method that poses little threat to health or the environment. The proper use of chlorination in the management of postharvest diseases in fresh fruits and vegetables is discussed.**

In a hungry and increasingly competitive world, the reduction of postharvest food losses remains a major agricultural goal. Investments to save food after harvest are usually less costly to the grower, the consumer, and the environment than efforts to increase production. In highly perishable crops, such as tomatoes, squash, and peaches, as much as 30% of the harvested crop may be lost to postharvest diseases before it reaches the consumer (Moline, 1984). Even a partial reduction in postharvest losses can reduce significantly the overall cost of production and lessen dependence on marginal land and other scarce resources.

Many factors contribute to postharvest losses in fresh fruits and vegetables, including heat and water stress, mechanical damage during harvesting and handling, improper postharvest sanitation, and poor cooling and environmental control (Moline, 1984). Efforts to reduce factors that contribute to postharvest losses are often very successful in reducing the incidence of rots. For example, a reduction in mechanical injury during grading and packing directly reduces the occurrence of postharvest decay because many disease organisms enter fruits and vegetables only via wounds.

Increased interest in efficient, gentle, and proper postharvest handling of fresh fruits and vegetables has prompted the widespread use of flumes, water dump tanks, spray washers, and hydrocoolers. In an effort to conserve water and energy, most postharvest processes that wet the produce recirculate the water after it has passed over the produce. This recirculated water picks up dirt, trash, and various decay-causing organisms (Boyette et al., 1992). If appropriate steps are not taken, the decay organisms can infect much of the wet produce. In the past, various fungicides and bactericides, alone or in combination with chlorination, were commonly used. These materials are favored over chlorination alone because some may provide residual protection after the treatment. Many of these materials have been removed from the market in recent years due to economic, environmental, or health concerns.

The use of chlorination presents one of the few chemical options available to help manage postharvest decay. When used in connection with other proper postharvest handling practices, chlorination may be an effective and relatively inexpensive postharvest decay control method. It poses little threat to health or the environment. This paper acquaints growers, packers, and shippers with the proper use of chlorination for management of postharvest decay in fresh fruits and vegetables.

Postharvest decays

There are many types of postharvest disorders and decays that affect fresh fruits and vegetables. Disorders are the result of stresses related to excess heat, cold, or improper mixes of environmental gases such as oxygen, carbon dioxide, and ethylene. Some disorders may be caused by mechanical damage, but none are caused by disease organisms and, therefore, are not affected by chemical treatments. However, disorders may weaken the natural defenses of fresh produce, making it more susceptible to decay caused by disease organisms (Sommer, 1992). Further, in many cases, injuries caused by chilling, bruising, sunburn, senescence, poor nutrition, and other factors can mimic diseases.

To control postharvest decays, it is necessary to understand the nature of these decay organisms and the factors that relate to their occurrence and capacity to cause losses. Postharvest decays may be caused by either fungi or bacteria, although fungi are found more often than bacteria in both fruits and vegetables. Postharvest decays caused by bacteria are rare in fruits and berries. Viruses seldom cause posthar-

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vest decays, although they, like postharvest disorders, may weaken the produce or affect its ability to ripen properly.

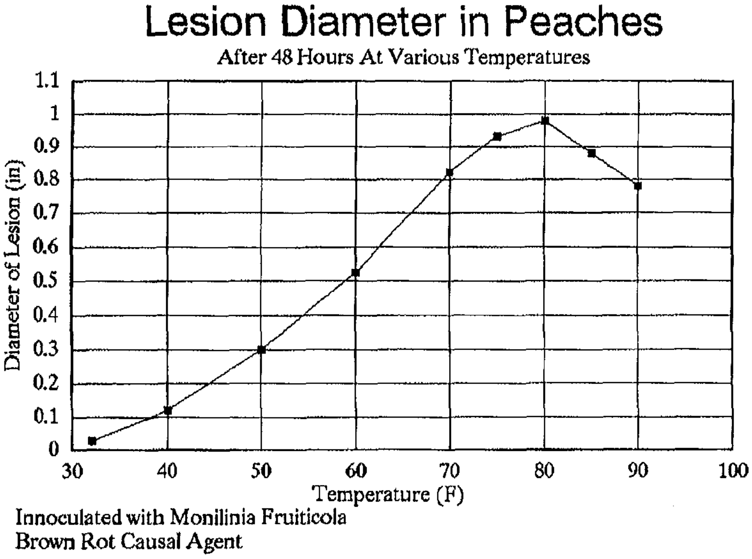

Fig. 1. *The effects of temperature on the growth of* **Monilinia fructicola** *(casual agent of brown rot) in ripe peaches. [Redrawn from: Brooks, C and J.S. Cooley. 1928. J. Agr. Res. 37507-5431*

Most postharvest fungal decays develop after spores formed by the actively growing pathogen land on the produce and germinate. Spores have adaptations that allow them to survive in hot, cold, or very dry conditions. They may be carried great distances by wind or water and can cover most exposed surfaces in great numbers. By contrast, bacteria responsible for postharvest decays are dispersed by water or fog-like droplets.

Either fungal spores or bacteria can remain relatively dormant on produce for long periods of time, until the correct combination of conditions occurs for their germination and growth. Alternatively, they can infect the produce, and the infections can remain latent. In all situations, a ripening or maturing product and a wet, humid atmosphere along with warm storage temperatures provide ideal conditions for resumed pathogen activity. The unbroken skin of fruits and vegetables provides a good defense against many decay organisms. Many immature fruits and vegetables contain chemicals that inhibit the growth of some decay organisms. Many of these chemicals and the resistance they provide are lost during ripening. Therefore, a fresh wound on the surface of a warm, wet, ripened fruit or mature vegetable, enclosed within a shipping container, provides an ideal site for attack by decay pathogens. Gentle handling to prevent wounding, and thorough cooling immediately after harvest, can reduce significantly the incidence of postharvest decay. Figure 1 illustrates the effects of temperature on the development of brown rot *(Monilinia fructicola)* in peaches (Brooks and Coley, 1928).

The goal ofchlorination is to prevent inoculation. Germinating spores are usually more vulnerable to control practices than are resting spores. After the pathogens have infected their host, chlorination is not very effective. Under the right circumstances, an infection of the host can be rapid, often taking only a few hours. Once active growth is underway and the organism has grown into the fruit or vegetable, chemical control is very difficult (Hardenberg et al., 1986). Table 1 lists some fruits and vegetables and common postharvest decays and their causal pathogens.

The potential for inoculation and infection by postharvest pathogens is always present when handling fresh produce. Understanding how these organisms come into contact with the produce can be helpful in formulating measures of control. There are several potential pathways by which this may occur.

Soil and field conditions. Decaying plant material in the form of discarded or unharvested fruits and vegetables contains huge populations of postharvest pathogens. Substantial pathogen populations may exist in soil under fruits and vegetables. Hard rains and wind can splash and distribute these decay agents onto unharvested produce. Warm, rainy conditions at the time of harvest greatly favor increases in disease development in the field (Sherman et al., 1981). The movement of decay organisms onto fruits and vegetables may even lead to inoculation and decay prior to harvest. Fruits andvegetables that appear healthy but, in fact, have already been infected are especially difficult to handle. Produce that has been inoculated or has latent infections is extremely difficult to handle. The question is not if the produce will decay, but when.

Contaminated water. The use of water from ponds and streams for postharvest cooling, fluming and washing must be strongly discouraged unless it can be properly treated. Irrigation with pond or river water is another way that fruits andvegetables are contaminated with decay. Muddy water or water taken from the bottom of the pond may be especially contaminated. Potable water from a well or another reliable supply always should be used if available.

Poor packing house sanitation. Pathogens brought into the packing house along with the produce will contaminate all working surfaces quickly. Decay-causing organisms attached to the tank walls, grading belts, brushes, and other surfaces can remain viable for months. All produce-handling equipment should be washed daily to remove dirt and decayed produce, and should be disinfected with an approved disinfectant on a regular basis. The packing house and immediate area surrounding it must be kept clean of any overripe or rotting produce. Culls should be taken immediately from inside the packing house and removed from the vicinity on a daily basis. The cull shoots and handling containers should be cleaned on a daily basis as fruit flies and other insects carry pathogens to other fruits and vegetables.

Air. Even the most meticulous attention to sanitation may not completely prevent contamination of fresh produce by decay organisms. Decay-causing organisms are present in the air and are opportunistic. They will infect produce if given suitable circumstances. The best defense against airborne pathogens is sanitation, consistent chlorination, proper handling of

Table 1. ***Some fruits and vegetables and their common postharvest decay and causal pathogens (Snowden, 1992; Moline, 1984).***

Commodity	Decay	Pathogen
Apples	Blue Mold	*Penicillium expansum* (f)[z]
	Gray Mold	*Botrytis cinerea* (f)
	Black Rot	*Botryosphaeria obtusa* (f)
	Bitter Rot	*Glomerella cingulata* (f)
Grapes and small fruit	Blue Mold	*Penicillium* sp. (f)
	Gray Mold	*Botrytis cinerea* (f)
	Rhizopus Rot	*Rhizopus stolonifer* (f)
	Mucor Rot	*Mucor piriformis* (f)
Potatoes	Fusarium Tuber Rot	*Fusarium* spp. (f)
	Wet Rot	*Pythium* sp. (f)
	Bacterial Soft Rot	*Erwinia* spp. (b)
	Slimy Soft Rot	*Clostridium* spp. (b)
Peaches and plums	Brown Rot	*Monilinia fructicola* (f)
	Rhizopus Rot	*Rhizopus stolonifer* (f)
	Gray Mold	*Botrytis cinerea* (f)
	Blue Mold	*Penicillium* sp. (f)
	Alternaria Rot	*Alternaria* sp. (f)
	Gilbertella Rot	*Gilbertella persic*aria (f)
Sweetpotatoes	Bacterial Soft Rot	*Erwinia chrysanthemi* (b)
	Black Rot	*Ceratocystis fimbriata* (f)
	Ring Rot	*Pythium* spp. (f)
	Java Black Rot	*Diplodia gossypina* (f)
	Fusarium Surface Rot	*Fusarium oxysporum* (f)
	Fusarium Root and Stem Rot	*Fusarium solani* (f)
	Rhizopus Soft Rot	*Rhizopus stolonifer* (f)
	Charcoal Rot	*Macrophomina* sp. (f)
Tomatoes and peppers	Alternaria Rot	*Alternaria alternata* (f)
	Buckeye Rot	*Phytophthora* sp. (f)
	Gray Mold	*Botrytis cinerea* (f)
	Soft Rot	*Rhizopus stolonifer* (f)
	Sour Rot	*Geotrichum candidum* (f)
	Bacterial Soft Rot	*Erwinia* spp. (b) or *Pseudomonas* spp. (b)
	Ripe Rot	*Colletotrichum* sp. (b)
Vegetables in general	Watery Soft Rot	*Sclerotinia* sp. (f)
	Cottony Leak	*Pythium butleri* (f)
	Fusarium Rot	*Fusarium* sp. (f)
	Bacterial Soft Rot	*Erwinia* sp. (b) or *Pseudomonas* spp. (b)

[z] *f = fungus, b = bacterium.*

the commodity, and quick and thorough cooling where appropriate.

Although the skin of fruits and vegetables offers considerable protection against infection, pathogens can enter produce through a variety of openings. Various wounds, such as punctures, cuts, and abrasions, as well as stems and stem scars, provide potential points of entry. The probability ofpathogen entrance into the produce increases with the size of the opening, the depth of submergence in water, the length of time in the water, the amount of surfactant in the water (true pesticide additives or detergents), and the water temperature. Even tiny natural openings (stomata, lenticels, etc.) can serve as pathways for decay organisms, particularly if the water-is soapy with surfactants (J.A. Bartz, unpublished data).

A small amount of surfactant added to the chlorinated water has been reported to enhance the effectiveness of chlorine against pathogens of pear. Yet, if tomatoes are infiltrated with water, even extremely high concentrations of chlorine cannot prevent postharvest decay.

The chemistry of chlorination

The use of chlorine or a chlorine solution as a disinfectant is known as chlorination, Chlorine is a very irritating, heavy, greenish-yellow gas with a very pungent odor. Free chlorine is very reactive, combining with any chemical that will react with oxygen. It is never found uncombined in nature. Chlorine gas is a very potent disinfectant, although it is seldom used in this form (Larch, 1987). It is much safer and easier to use when dissolved in water.

Chlorine for use in water chlorination may be obtained in one of three of the following forms.

Chlorine gas. Chlorine gas is produced by the electrolysis of salt solutions (principally NaC1) and is furnished commercially as a liquid in pressurized metal cylinders. Chlorination is accomplished by bubbling a metered amount of the gas into the supply water. Because of the danger involved with the use of chlorine gas and the expense of the metering equipment, the use of chlorine gas for chlorination usually is limited to larger applications. Most municipal water supplies are chlorinated with chlorine gas.

Calcium hypochlorite. Calcium hypochlorite is a common form of chlorine used in postharvest chlorination. It is available commercially either as a granulated powder or in the form of large tablets. Most commercial formulations are 65% calcium hypochlorite, with the balance being stabilizers and inert materials. Calcium hypochlorite is relatively stable as long as it is kept free from water and may be stored for extended periods in solid form (Sawyer, 1978). The property that makes it stable also makes it difficult to dissolve completely in water. Adding granulated calcium hypochlorite directly to the water often results in undissolved particles that adhere to the produce, which then causes undesirable bleaching and chlorine burns. This is particularly true in hydrocoolers because calcium hypochlorite is very slow to dissolve in cold water. Therefore, granulated calcium hypochlorite always should be dissolved in a small quantity of tepid water before adding it to the wash tank or hydrocooler.

Calcium hypochlorite may be obtained in tablets that are added directly to the hydrocooler or wash tank to eliminate the problem of chlorine burns. Properly used, it will slowly dissolve to yield a continuous supply of chlorine to the water. However, care should be exercised in the placement of the tablets to ensure proper mixing of the chemical and the water.

Sodium hypochlorite. The active ingredient of most liquid household bleach, sodium hypochlorite, is used commonly when the scale of postharvest chlorination is limited. Sodium hypochlorite in solid form is not generally available for postharvest applications because it is difficult to store. It will readily absorb moisture from the atmosphere, causing it to release chlorine gas.

Household bleach usually is marketed as solution of water and 5.25% sodium hypochlorite. Commercial bleach containing from 9.5% to 15% sodium hypochlorite solutions are also available fromvarious chemical suppliers. These products come in large containers and are not as stable as household bleach. For the same amount of chlorination, a sodium hypochlorite solution is generally more expensive than granular calcium hypochlorite due to the additional shipping and handling costs associated with the water.

In addition to mixing and adding the chemicals to the water manually, concentrated solutions of sodium or calcium hypochlorite may be injected into the wash tank or hydrocooler at a continuous and measured rate. Chlorine injector systems are commercially available that are particularly useful in operations where a continuous supply of clean chlorinated water is required. Injector systems consist of a feed tank and an electrically operated pump with a variable output. Chlorine injectors should always be isolated from water supply lines with an approved check valve arrangement to prevent backflow into the fresh water system.

A chlorine concentration of about 55 to 70 ppm at pH 7.0 with a water temperature of 104F (40C) is recommended to sanitize most fruits and vegetables. Higher concentrations are required with higher pH and lower solution temperature. Chlorine may need to be added to the solution more often if the pH is higher and if the temperature of the solution is >80F (26.7C). In actual practice, recommendations of up to 100-150 ppm of free chlorine and more have been reported (Rushing, 1986).

Factors that influence the level of chlorination activity

Chlorination is a dynamic chemical process. The efficiency of the chlorination process is ever-changing and is influenced by a number of factors. Proper chlorination requires frequent monitoring of the solution and a thorough understanding of the factors involved. These factors include the following.

1) Changes in pH. The pH of a solution is a measure of its acidity or alkalinity. A solution that is neutral (neither acid nor alkaline) has a pH of 7.0. Solutions with pH numbers 17.0 are acid-the lower the number, the greater the acidity. On the other hand, the greater the number than 7.0, the more alkaline the solution. A change of one pH unit indicates a lo-fold change in the acidity or alkalinity.

The pH of the solution has a significant effect on the activity of chlorination in water. When chlorine gas or one of the hypochlorite salts is added to water, each will generate chlorine gas (Cl_2), hypochlorus acid (HOC1), or hypochlorite ions ($OC1^-$) in various proportions, depending on the pH of the solution. The form desired for chlorination is HOC1. Hypochlorite ions are relatively inactive and chlorine gas will bubble quickly from the solution, causing worker discomfort and serving no useful purpose (Sawyer, 1978).

At a pH slightly above neutral, half of the chlorine will be in the form of HOC1 and the other half in the form of $OC1^-$. To maximize the proportion of hypochlorus acid and, hence, the effectiveness of the solution, the pH should be kept in the practical range of 6.5 to 7.5 (Rushing, 1986).

Because the pH of potable water supplies may vary from moderately acid to moderately alkaline, the water should be checked with a pH meter or test papers before and after the chemicals are added and frequently during operation. Various stabilizers such as sodium bicarbonate or sodium carbonate, included in many commercial chlorine products, may have a major influence on the pH changes associated with different treatment systems. Further, even if the water has a near-neutral pH, the addition of hypochlorites will cause changes in the pH. Different sources of chlorine have different effects on pH:

- Chlorine gas decreases pH.
- Sodium hypochlorite increases pH.
- Calcium hypochlorite increases pH slightly.

The addition of muriatic acid (HC1), often used in swimming pools, may be necessary to lower the pH. Small amounts of sodium hydroxide (NaOH, lye) may be used to raise the pH. Inexpensive test paper for checking both the chlorine level and pH may be obtained from most swimming pool and chemical supply houses.

2) Concentration. The concentration of a small amount of chemical in a solution may be conveniently described by the term “parts per million” (ppm). In the case of chlorination, ppm indicates the number of units of available chlorine, by weight, there are in a million units of solution. The quantity of calcium or sodium hypochlorite that must be added to a certain quantity of water in order to maintain a given concentration depends on:

- the available chlorine content of the compound,
- the concentration of the compound,
- the volume of water to be treated, and
- the amount lost due to the reaction with chemicals in the water; i.e., the chlorine demand.

Tables 2 and 3 give amounts of sodium hypochlorite solution and calcium hypochlorite granules to obtain a specified concentration of available chlorine in ppm.

3) Temperature. The activity of chlorine increases as the temperature of the solution increases. In hydrocooling situations where the water temperature is low, there may be a significant reduction in chlorination efficiency.

4) Organic matter. Chlorine has a particular affinity for organic matter. Chlorination of dirty produce “uses up” the available chlorine much faster than relatively clean produce. The amount of free available chlorine in the solution constantly decreases with chlorination reactions. The more organic matter in the tank (fruit, leaves, muck, etc.), the more chlorine is lost. As a result, the chlorine level should be checked and renewed regularly, especially when large loads of produce are being processed. In instances where the produce is extremely dirty (root crops, for example), it is a common practice to wash them with clean water before putting them into the chlorination tank (Sherman et al., 1981).

5) Time. The effectiveness of the chlorine treatment depends greatly on the length of exposure time. Quick dips are much less effective than longer exposures. However, most of the sanitizing action of the chlorine will be accomplished within the first several minutes of exposure. Prolonged exposure to strong chlorine solutions has been known to cause surface bleaching. Experience is the best guide to the correct combination oftreatment time, concentration ofchlorine, and the crop being processed.

6) Growth stage of the pathogen. Decay organisms may be either in the active vegetative form or in the form of spores. Chlorine will kill readily the vegetative form, but some fungal spores are 10 to 1000 times more difficult to kill. Therefore, the chlorine treatment will rarely eliminate all pathogens and sterilize the surface of the produce. Many spores may remain on the surface to develop later should the opportunity arise. Further, chlorine kills only on contact, not systemically, and is only effective on exposed pathogens such as those suspended in water or those on the surface of produce; chlorine does not kill pathogens it cannot contact below the surface of the produce. Chlorination leaves no residual effect (Sawyer, 1978). Therefore, produce exposed to pathogens after treatment is susceptible to reinfection.

Wastewater quality considerations

Spent chlorinated water customarily is dumped at the end of each work day, or more often if the circumstances dictate. This liquid may contain concentrations ofsediment, pesticides, and other suspended matter. It may be considered an industrial wastewater if the product is discharged to a municipal wastewater treatment plant or to surface waters (canals, creeks, or ponds). Land application of this material may be permitted, but a nondischarge permit may be required. An operator may be required to obtain a discharge permit. Anyone using or planning to use chlorination should check with their local officials. The illegal disposal of spent chlorinated water may result in a substantial penalty.

Table 2. ***Pints (liters) of 5.25% sodium hypochlorite (NaOCl) solution required to obtain a specified concentration of available chlorine in 100 gal (1000 liters) of water (neutral pH).***

Pints/ 100 gal	Liters/ 1000 liters	Approximate available Cl concn. (ppm)
0.4	0.5	25
0.8	1.0	50
1.2	1.5	75
1.6	2.0	100
2.0	2.5	125
2.4	3.0	150

Table 3. ***Ounces (grams) of 65% calcium hypochlorite [Ca(OCl)$_2$] granules required to obtain a specified concentration of available chlorine in 100 gal (1000 liters) of water (neutral pH).***

Ounces/ 100 gal	Grams/ 1000 liters	Approximate available Cl concn. (ppm)
0.5	37.5	25
1.0	75.0	50
1.5	112.5	75
2.0	150.0	100
2.5	187.5	125
3.0	225.0	150

The Environmental Protection Agency (EPA) regulation of 8 May 1991 (40 CFR part 180) exempts calcium hypochlorite and chlorine gas when used pre- or postharvest on all raw agricultural commodities from the requirement of a tolerance for residues. The U.S. Food and Drug Administration specifies that an aqueous solution containing not more than 200 ppm of available chlorine may be used to sanitize food-processing equipment (Schlimme, 1991). However, excessive chlorine levels can damage equipment, injure the surface of fruits and vegetables, and is an unnecessary waste. Additionally, the use ofexcessively high amounts of chlorine may pose a worker health and safety hazard.

Practical rules for successful chlorination: A summary

1) Closely evaluate the need to use water to handle the produce. Wetting the produce greatly increases the likelihood of infection and spread of postharvest decays. There may be no alternative to water for cleaning dirty root crops, etc. Even hydrocooling may be a necessary practice, although alternative methods, such as forced-air cooling, may be a viable and non-wetting option in some situations.

It is advisable to evaluate closely the need for water in the handling of produce vs. the risk of decay. If water is not necessary in the packing process, do not use it. When water is necessary in packing lines (dumping tanks, flumes, hydrocooler, etc.), it always should be treated to reduce risk of rots.

2) Monitor the chlorine concentration and the condition of the water. Chlorine concentration and pH should be monitored frequently by the use of test papers or electronic equipment. Automatic chlorination equipment is available that will monitor continually the condition of the solution, add chlorine, correct the pH, and maintain water temperature.

3) Avoid overexposure of produce to water. Do not allow the produce to remain in contact with the solution longer than necessary, as surface-bleaching may occur. Additionally, water-logged produce is much more likely to decay no matter how much chlorine is used. Be sure that the produce is not left standing in chlorinated water for extended periods. Evaluate product circulation patterns in chlorination tanks to eliminate "dead" spots.

4) If possible, change the water frequently. The chlorination efficiency is poor with very dirty water. If necessary, very dirty produce should be washedwith clean water before it comes in contact with the chlorinated water.

5) Plan water disposal. Before chlorination equipment is installed, disposal of the wastewater needs to be planned. Land application of waste water normally is allowed, but operators should check to see if a permit is needed. Illegal disposal of chlorinated water could result in a substantial fine.

6) Practice good sanitation. Hose off the packing equipment and floors daily and remove the dirt and trash that may have settled in the chlorination tank. Equipment may be sanitized with a spray of four pints of 5.25% sodium hypochlorite solution in 10 gal of water. There are other approved disinfectants for food processing equipment. Alternatively, equipment may be steam-cleaned with an approved detergent. Do not allow culls or decayed produce to remain in or around the packing house.

7) Ventilate the packinghouse. Levels of chlorine great enough to cause worker discomfort are excessive and well above that required for proper postharvest sanitation. In the absence of air-monitoring equipment, chlorine concentrations are usually adequate if they can be smelled by a person not desensitized by long exposure to the odor. The concentration is too high if workers are irritated continually by the odor.

8) Practice all aspects of proper postharvest handling. Chlorination will not solve all your problems. Even the best-executed chlorination program may not be sufficient to prevent all postharvest decay. Prompt removal of field heat and proper sanitation should be part of all postharvest decay management programs. Produce infected or otherwise damaged in the field will not be saved by chlorination.

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