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Guide to Identifying and Controlling Postharvest Tomato Diseases in Florida[1]

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The disease issues faced by tomato growers in the field are of a wide and dynamic scope and numerous publications describe control measures for field diseases. The potential for postharvest decay is no less severe and may even be more dramatic. However, the mode of action of postharvest pathogens is often very different from those of field pathogens and few resources are available.

Prior to harvest, tomatoes are part of a living organism with natural defenses and resistances to many opportunistic pathogens. These pathogens are generally ubiquitous (found everywhere) microorganisms that require some weakening in the fruit tissue, such as a wound, before they can cause disease or decay. Mechanical damage at harvest makes tomatoes more susceptible to infection by pathogens. Fruits and vegetables vary in their susceptibility to decay: those that form a natural abscission layer at the stem, such as tomatoes and melons, are more resistant to pathogen attack than, say, broccoli, which is cut from the plant, leaving unprotected internal tissues exposed to infection through the wound.

Once harvested, a tomato has limited postharvest life. It no longer receives water or photosynthates from the mother plant. It is far less capable of fending off attacks by decay pathogens and is also more easily bruised which, in turn, weakens tissue and further adds to susceptibility to decay. Senescent processes also reduce postharvest life as the tomato consumes its own energy reserves to maintain vital life processes. It is in this fragile state that the greatest care must be taken to protect tomatoes from the many potential causes of decay.

What are these agents of decay? Where do they come from and how do they survive? How can they be avoided or eradicated to avert loss?

There are numerous microorganisms that can cause postharvest tomato decay and that are nearly ubiquitous in nature.– This is the bad news. The good news, however, is that regardless of the many ways that decay pathogens can cause infection, all of these organisms can be controlled through the implementation of an appropriate sanitation program.

This bulletin is designed to supplement field scouting and identification guides by 1) describing

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postharvest decay pathogens important to Florida tomato packers and shippers, and 2) presenting sanitation guidelines for minimizing the accumulation of pathogens during harvest and handling operations.

Identifying Postharvest Pathogens

The two primary classes of microorganisms that cause decay are bacteria and fungi. Two other types of plant pathogens, viruses and nematodes, do not cause postharvest decay. However, preharvest viral infections can disfigure tomatoes or cause ripening abnormalities that make them unmarketable. An important example is tomato spotted wilt virus (TSWV), which can cause nearly invisible color changes in green tomatoes that later fail to ripen properly and lead to market rejections.

Postharvest Diseases Caused by Bacteria

Bacteria are single-celled organisms that can rapidly multiply and spread, particularly in water. Even a thin film of water, such as wet fruit, leaf, or packinghouse machinery, can support rapid bacterial growth. Bacterial growth is often slimy, with no uniformity. Films may form on surfaces and become sticky with age . Fresh films normally disperse readily in water, whereas older formed films resist wash efforts (see the Dump Tank "Sanitation section").

Bacteria cause one of the most common, and potentially devastating, postharvest diseases in Florida tomatoes. This disease, bacterial soft rot, causes fruit tissue to become liquefied, with associated complete loss of texture (Figure 1). Bacterial soft rot can be caused by at least four different bacteria.

The most common and most aggressive "soft rot" bacteria are strains of *Erwinia carotovora* subsp. *carotovora*. These bacteria are ubiquitous and have been found in places as diverse as ocean spray off the coast of California, snow in the Rocky Mountains, well water in a few locations, and surface water nearly everywhere. The soft rot Erwinia can grow on the surface of plants and cause a soft rot of succulent plant parts, particularly during wet weather.

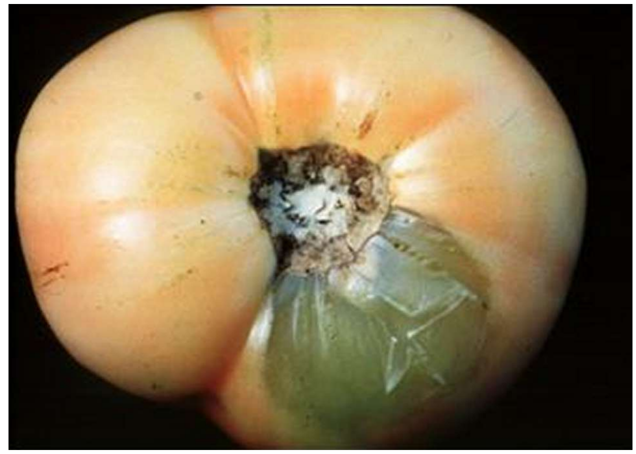

Figure 1. A typical bacteria soft rot.

They can be spread by rainstorms, insects, harvest crews, picking containers, and packinghouse equipment. Fortunately, these bacteria cannot penetrate directly through the waxy skin of a tomato. However, small wounds, even the size of abrasion from sand particles, during harvest, are large enough to admit a bacterium and lead to infection and decay. Additionally, unwounded tomatoes can become infected by unsanitary wash or flume water through infiltration of the stem scar, blossom scar or wounds, allowing the bacteria to cause interval decay (Figure 2).

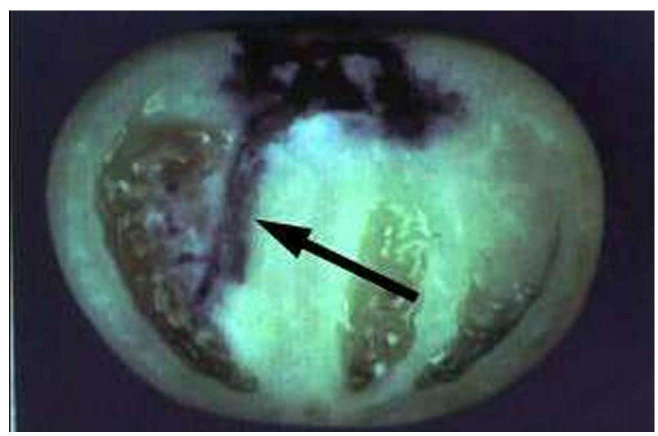

Figure 2. Infiltration of black dye through stem scar.

Other potential causal agents of bacterial soft rot include some member species of *Pseudomonas, Xanthomonas* and *Bacillus.* The mode of action, symptoms and control for these pathogens are nearly identical to those for *Erwinia*. Since these organisms readily disperse in solution, they are quickly moved by liquids such as the water in dump-tanks, flumes or washers, or in the juice from decayed fruit. Soft rot bacteria can even grow through the fiberboard of a shipping carton soaked with the rotten material of decayed fruit. If a rotten fruit, or the liquid from a rotten fruit, is allowed to come into contact with another fruit, either directly, through dump tank water, or by being passed along over equipment or a worker's hands, the new fruit becomes contaminated with bacterial cells and may succumb to disease (especially if wounded). High relative humidity (90-95%) that is recommended for tomato ripening storage and shipping can promote rapid bacterial growth, especially if the tomatoes were not completely dried prior to packing.

A second type of bacterial decay that was discovered relatively recently is a sour-rot type disease caused by bacteria that produce lactic acid. These organisms are also ubiquitous in nature and are similar to those responsible for the pickling process in cucumber. Several environmental and fruit samples recently collected by the author from different packinghouses contained these bacteria. They are potentially present on equipment, on fruit coming in from the field and in the liquid from rotting fruit. In laboratory tests with tomatoes, these bacteria produced a slightly softened lesion like the other soft-rot bacteria, but the wound liquid was quite acidic and smelled as if the tissues had been pickled. Unlike the sour-rot disease caused by fungi, there was no evidence of fungal growth, however, gram-positive bacteria were found in the affected tissues.

Food Safety Considerations

Human pathogens can (bacteria and viruses) contaminate tomatoes through contact with infected workers, domestic and wild animals, raw manure, contaminated equipment/ containers/trucks, and rain splash from nearby pastures or animal confinements. These bacteria are dispersed similarly to the fruit rotting organisms (through liquid, on a workers hands, etc.). However, since human pathogens do not visibly affect the fruit, their presence will not be detected unless there is an outbreak of disease among people consuming the fruit. Fortunately, the same sanitation steps that control fruit-rotting pathogens will normally control human pathogens as well. These steps include animal exclusion programs, maintaining sanitary employee restroom and hand washing facilities, and constant sanitation of reused water and equipment. For more information, see the references listed at the end of this publication.

Postharvest Diseases Caused by Fungi

Fungi are filamentous microorganisms commonly known as molds. In nature, they often appear thread-like or cottony. Many fungal species can cause fruit decay in tomatoes and, like bacteria, usually flourish in moist conditions. Fungi are generally more difficult to eradicate for a few reasons, but primarily due to the ability to produce spores that are highly resistant to drying and other environmental stresses. Spores are resilient, single- to few- celled reproductive structures that resemble seeds in their method of action. Although spores cannot swim like bacteria, they are produced in large numbers and can be spread by air currents as well as moving water and biotic vectors such as insects or animals.

The sour-rot pathogen, *Geotrichum candidum*, actually belongs to the yeast family. Its growth resembles a thick, gelatinous mass similar in appearance to cottage cheese growing on the surface of a liquefying fruit (Figure 3). As is indicated by the name, a distinctive sour odor is produced.

A second very common fungal pathogen is *Rhizopus stolonifer*. This fungus resembles bread mold in appearance and it grows *very* aggressively even under refrigerated conditions. A tomato infected with Rhizopus rot appears water-soaked under the skin producing liquid similar to that of the bacterial diseases, but it is usually covered with thin, cotton-like fungal structures (especially under humid conditions). After infection, a fruit will usually maintain its shape for a longer period of time with bacterial soft-rot infections, as the filamentous nature provides temporary structural support. If such a fruit is gently broken apart, strands of the fungus can be seen in the decaying tissues. On the fruit surface, a dark area of sporulation often crowns the white tuft of *Rhizopus*. The mycelium (thread-like fungal structure) can infect adjacent fruit through natural openings or mechanical wounds creating nests of mold and diseased fruit (Figure 4). The spores are extremely small and lightweight, and can be carried by air currents to infest new fruit, potentially far from the source. *Rhizopus* has been reported to grow short distances over dry surfaces, such as pallets and boxes, to infect new fruit.

Figure 3. A roma tomato with Geotrichum sour-rot.

Figure 4. A carton of fruit with "nested" *Rhizopus* rot (and some secondary fungi).

Other, less-common, fungi that may attack Florida tomato fruit:

Phytophthora usually causes a circular rot that looks water-soaked, later darkening in the center and/or becoming overgrown with sparse, white mycelia (Figure 5). It is often on the stem-end, or on the side of the fruit closest to the soil.

Alternaria produces dark, irregularly shaped lesions and usually grows only when there has been some other type of injury such as sun scald, blossom-end rot (calcium deficiency), some type of mechanical injury or chilling injury (Figure 6). Also,

Figure 5. Different stages of *Phytophthora* rot (similar to *Phoma* rot).

Alternaria may be seen in older, ripe tomatoes that have skin cracks and are beginning to decay due to age. It is most common in fruit that have been stored for extended periods of time.

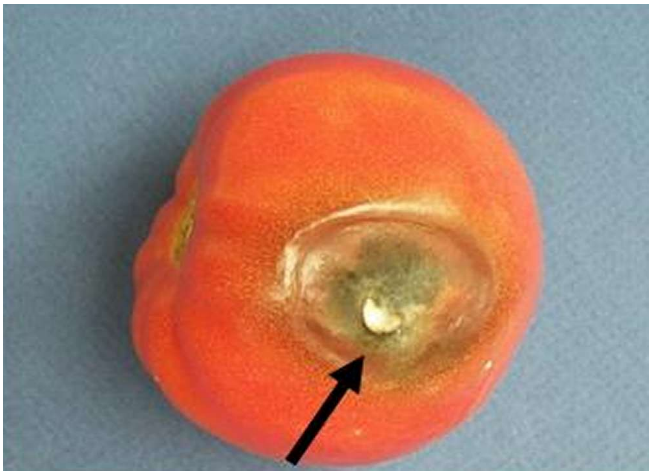

Figure 6. A fruit with a fingernail wound (arrow) that later developed into *Alternaria* rot.

Fusarium (Figure 7) is less common than *Alternaria*, but it can infect a tomato in a similar fashion. It usually grows on fruit picked at the red stage, especially those that have fallen from the plant or were otherwise in contact with the soil. Its lesions are fluffy white with undertones ranging from shades of pink or orange to purple.

Several fungi can infect tomato fruit in the field, which later leads to postharvest losses. Target spot (Corynespora cassiicola) develops on tomatoes (plants and fruit) during long periods of high moisture and warm ambient temperatures. Fruit lesions are small, dark brown spots that enlarge and split open as the fruit ripens. Phoma rot (Phoma destructiva) begins at the blossom end of fruit as sunken black spots with water-soaked edges and dark-centered rings. Anthracnose, caused by Colletotricum spp. on primarily ripe-to-overripe fruit, can appear during wet conditions. Cladosporium rot, caused by Fulvia fulva, develops under highly humid conditions, usually in greenhouses. Gray mold and the less severe disease, ghost spot, are caused by Botrytis cinerea in fruits grown in cooler climates and greenhouses. As a group, these fungal fruit rots appear sporadically in Florida causing field losses and decreased packouts. At harvest, some of the fruit infections can be latent or appear as tiny lesions that escape detection on the packing line. However, the infections continue to develop during shipping and marketing, causing the affected fruit to become unmarketable. The diseases rarely or never spread among packed tomatoes, but can provide entry points for pathogens causing diseases that do spread, such as rhizopus rot or sour rot.

Figure 7. *Fusarium* originating from the stem-scar.

Dump Tank Sanitation

Ideally, harvest crews follow good management practices and don't pick decaying fruit. This is not always the case, however, so the dump tank presents the greatest potential for contaminating tomatoes if pathogens accumulate in unsanitized water (Figure 8). To combat this, tomato packers have used preventative programs for water sanitation for many years. “Vigilance” is the key word in preventing decay. In the following section, key considerations are presented for establishing and maintaining sanitary conditions during tomato packing.

Figure 8. *Geotrichum* sour rot on a Roma tomato taken from a flume. This fruit is an excellent source of inoculum that may infect other fruit in the flume and cause further decay.

1) Pathogen Population. It is never known when a large pathogen population will be introduced into the dump tank. It is entirely possible that a full season may pass with the absence of significant populations of decay pathogens. We have documented this recently when extremely low pathogen populations were encountered during an extended drought. When pathogen populations are low, packinghouses with poor sanitation practices may receive few decay-related rejections of shipments. Conversely, at other times, every load received at the packinghouse could contain high decay pathogen populations. If water sanitation is not maintained, there could be significant losses due to postharvest decay during shipping. Postharvest decays are invariably associated with wet field conditions. With the number of tomato fields and their great variability in daily environmental conditions, an accurate system for forecasting pathogen populations is not yet feasible.

Fortunately, preventative measures can be implemented that will safeguard against the accumulation of bacterial pathogens, fungal pathogens, or human pathogens. These measures address the control of the most resistant pathogens: fungal spores. By controlling fungal spores, the less resistant pathogens (bacteria, *including human pathogens*) are controlled by default.

2) Effective Water Sanitation. Maintenance of 100 ppm to 150 ppm *free* (also known as available or active, not to be confused with "total") chlorine at a neutral pH (~6.5 to 7.5) is the recommended treatment of dump tanks, flumes, and washers. Several treatments have been suggested as alternatives to water chlorination. However, to date, none have matched the ease of use, cost effectiveness, and sanitizing ability of chlorine. Caution must be exercised at all times with chlorine; it is highly reactive, and can be harmful to workers if not used properly.

As tomatoes are introduced into the dump-tank, leaves and soil also enter the water. Free chlorine reacts quickly with this organic matter plant and fruit surfaces as well as with soil or other inanimate matter. The products of these reactions make chlorine ineffective in killing microbes. Therefore, *free chlorine* concentration and NOT total chlorine concentration must be measured to determine the efficacy of the biocide in the tank. **Only *free* chlorine will destroy microbes.** To further understand the difference between free and total chlorine, one can imagine a room full of chairs. With no one in the room, all of the chairs, the *total* number of chairs, are empty, or *free*. If several people come into the room and sit down, there is still the same *total* number of chairs present, but not as many chairs remain empty, or *free* for more people to sit in. As more people enter the room, all of the chairs eventually become occupied. This is similar to the free chlorine in the dump tank. As it reacts in the water, less is available for sanitizing and more free chlorine must be added to the water.

Effective water chlorination is also dependent on the pH of the water. Maintaining neutral pH (~6.5 to 7.4) maximizes efficacy of chlorine. Lowering the pH below 5 increases the amount of free chlorine, but can also increase off-gassing, accerlate the rate at which chlorine is lost from the system (increasing the amount that must be added) and enhance corrosion of equipment. Alternatively, raising the pH above 7.5 reduces chlorine's efficacy.

A more thorough explanation of chlorine chemistry, pH effects and mixing guidelines is available (Ritenour, Sargent and Bartz, 2000).

3) Monitoring Dump Tanks. There are two methods for determining the free chlorine concentration in dump-tank water. The first method is a "free-chlorine test kit," similar to those used to measure free chlorine in swimming pools. These test kits are relatively inexpensive and offer a quick way to manually measure free chlorine. Kits are available from various vendors for a variety of ranges of concentrations. Many of these kits only read in a low range, not high enough to measure dump-tank concetrations. These kits require that the sample must be diluted in distilled water and the results altered to account for such a dilution. There are also kits that use test strips to measure free chlorine.

The second method is the use of an electronic probe to determine Oxidation-Reduction Potential (ORP) in the water (Figure 9). This type of probe measures the electrical potential in the water. The amount of free chlorine changes the electrical potential, which in turn correlates to an estimate of free chlorine content. The addition of organic matter, off-gassing, dilution, or other loss of free chlorine from the system reduces the measured electrical potential.

It is also important to minimize infiltration of dump tank water (and any potential accompanying pathogens) into the tomato. Heating dump-tank water 5^oC (about 10^oF) above tomato pulp temperature has been shown to reduce infiltration through the stem-end or blossom-end scars and skin breaks and, therefore, reduce postharvest decay.

Tomatoes should be kept in the water for two minutes (one to three minutes). This assures sufficient contact with the sanitizer, while avoiding extended soaking time that can increase water uptake.

For effective sanitation, the dump tank must be frequently monitored for free chlorine, pH and water temperature throughout the packing day. Automated systems using ORP and pH probes are commonly used in the industry, but manual readings should still be made and recorded every 30 minutes to an hour to ensure proper equipment operation. Record keeping is critical for trace-back and evaluation/resolution should a decay outbreak, occur during later handling,

Figure 9. A handheld ORP/pH meter with ORP probe reading a standard.

shipping or marketing. Hand-held electronic mV and pH meters, free chlorine test kits, and free chlorine are very reliable for this purpose.

4) Reducing Other Sources of Pathogens. Dump-tank water is not the only potential source of pathogen inoculation of fruit. From field to packinghouse, tomatoes can be held a significant amount of time in field bins before being unloaded. Improper or careless handling during harvest or bin filling/dumping operations can cause serious mechanical damage. Some damage is obvious and is culled by sorters on the packing line. However, some other damage is nearly invisible without close inspection. A good example is the scraping wounds due to fruit rubbing rough bin walls, or abrasion caused by sand grains. Abrasions and microperforations can directly inoculate the tomato. Sand is most common, but dried plant material, attached stems, wood splinters on bins, etc. can also be causal agents. Open wounds can also become infected later by other pathogens.

An active bin sanitation program is important to the success of any packing operation. Sanitation is best achieved by pressure (or steam) rinsing bins with a sanitizer on a daily basis. Bins that are least likely to harbor pathogens are wooden bins that have smooth painted inner walls. Plastic bins are preferred over unpainted wooden bins because, although cleaning sanitizes the surface of wooden bins, pathogens can infiltrate the wood and become protected from the sanitizing process. These embedded pathogens can become active later when moistened by fruit sap, dew, or rainfall and later grow out and infect stored fruit. Plastic bins are impervious to infiltration and minimize this problem. Bin maintenance is critical. Paint can wear off or be chipped off and pathogens can infiltrate into the exposed wood. This may, in the long run, prove less cost effective then the initial investment of plastic bins.

Postharvest decay can also develop during ethylene gassing. While pathogen inoculation has not been reported as occurring during gassing, the gassing room is an excellent environment for any existing pathogens to grow, multiply, and spread. Recommended ripening conditions, 20 to 22^{o}C (68 to 72^{o}F) and 90% relative humidity, are unfortunately very favorable conditions for growth of most decay pathogens, both bacterial and fungal. Harvest maturity is very important in maximizing postharvest life and quality. If tomatoes are harvested at the mature-green stage, they should reach breaker stage (10% red color) in three days or less of gassing. At this point they will ripen to normal flavor and color during later handling and shipping at 12^{o}C (53^{o}F) or above. However, tomatoes harvested at the *immature* green stage require extended time (more than five days) in the gassing room. This excessive ripening chamber time should be avoided as it has been reported to result in increased incidence of fungal decays at tomato stem-end scars.

Another reason to minimize the number of inmature tomatoes harvested relates to quality. Studies with trained taste panelists have shown that tomatoes that reached breaker stage within three days of gassing taste better and had better color than those that required four or five days of gassing (Sargent *et al*, 1998). Those tomatoes that required 5 days or more of gassing to reach breaker stage were considered "inedible by the panelists."

Summary of Recommendations

Based on the above discussion, the following guidelines summarize an effective packinghouse sanitation program:

To maintain effective dump-tank sanitation, the water must have the following conditions constantly:

- Maintainfree chlorine (*not* total chlorine) at 100 to 150 ppm and neutral pH (6.5 to 7.4).
- Maintain water temperature at 5°C (about 10° F) above tomato pulp temperature.
- Keep tomatoes immersed for 2 minutes (1 to 3 minutes) to maximize pathogen kill while minimizing water uptake.
- Avoid allowing fruit to float in stagnant water during crew breaks or for longer periods of time; this includes elimination of "dead spots" in the flume system.
- Fruit immersion should be no greater than two layers deep, ideally only a single layer, to minimize infiltration.
- Use an automated system for chlorine and pH control, with manual measurements recorded each 30 minutes to an hour.
- Drain dump tank, sanitize, rinse and refill with potable water daily water.
- Follow local regulations on disposal of treated water, and comply with all chemical labels (for chlorine, acidifier, etc.); *the container label is the law*!
- Tomatoes should be gassed no longer than 5 days; 3 days is the preferred maximum for best quality. Tomatoes gassed in bulk should be washed and presorted prior to placement in the gassing room to minimize decay.
- Plastic bins are more easily sanitized than unpainted wooden bins. Surfaces that directly or indirectly contact tomatoes should be regularly cleaned and sanitized (picking buckets, bins, gondolas, packing line components, pallets); gassing and holding rooms walls, floors, refrigeration coils should also be regularly cleaned).
- Sanitizers such as quaternary ammonia compounds work well on equipment but are *not* approved for direct contact with foods. Bin and packing line surfaces treated with these compounds can cause chemical injury to tomatoes and should be thoroughly rinsed with water prior to contact. Dump tanks cleaned with ammonia compounds should be thoroughly rinsed with water prior to filling. *Note: ammonia compounds react quickly with chlorine to form noxious gases.*
- Hand washing facilities should be available at all handling points, beginning in the field. Employees should wash their hands *thoroughly* with soap after each restroom use. Commercial hand sanitizers are good supplements to such washing, but are not effective sanitizers when used alone.

Sanitation must be effective at each step from harvest through handling - the adoption of only one recommendation from the above list is not sufficient for adequate control of decay pathogens. Each step adds a *small* amount of preventative control, which in conjunction with the other steps, act together to build to an effective BMP for packinghouse sanitation.

For Further Information

U.S. Dept. of Health and Human Services. Center for Food Safety and Applied Nutrition 1998. Guide to minimize microbial food safety hazards for fresh fruits and vegetables. Washington DC. (www.foodsafety.gov/%edms/prodguid.html)

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