

Postharvest Quality and Decay Incidence among Tomato Fruit as Affected by Weather and Cultural Practices. ¹

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Postharvest decay losses for field-grown, fresh-market tomatoes are usually associated with harvests that occur when fields are wet and warm (> 90°F daytime). During periods of persistently wet fields (plant foliage is continuously wet for 24 hours or longer), decay pathogens infect damaged fruit on the plant as well as injuries to petioles and stems. During harvest, enormous pathogen populations created by these infections spread via picking operations throughout the harvested fruit. Inadvertent harvest-related wounds are particularly vulnerable to infection. Growers and packinghouse managers may have to struggle to salvage their crops. With the exception of gray mold (caused by *Botrytis cinerea*) (not a major problem in Florida tomatoes), most tomato decay pathogens are more active during warm temperatures. However, weather transition periods in which average field temperatures change significantly because of weather fronts can also lead to postharvest decays, particularly if plant canopies remain wet for several hours each day. What qualifies as a significant change in temperatures is unclear. However, clues that this has happened include dense fogs and wet plants. Persistent canopy wetness is not always attributed to rainfall. Dense fogs in the morning can prevent wet plants and fruit from drying. Heavy dews, which are often accompanied by extensive guttation (in which water forced into plants by root uptake exits through leaf hydathodes), also can produce a persistent wetness even without fogs. Some postharvest problems

that appear to be associated with weather transitions are described below.

During the winter production seasons of 2010 and 2011, cold temperatures in the field were associated with postharvest defects that reduced fruit quality and increased decay. In 2010, according to newspaper accounts, 70% of South Florida tomato production intended for late winter/early spring harvest had been lost to frosts and freezes by the end of January. Harvested, surviving fruit were of low quality, and the situation did not improve until mid-April. Our review of photographic records concerning fruit quality and decay losses during that period as well as records dating back to 2002 revealed consistent correlations between certain defects and postharvest decays. These same defects and accompanying decays have also been observed during periods of warmer field temperatures. All Florida production areas have experienced these problems at one time or another. Specifically, fruit had surface russetting and/or weather checking (cuticle cracks) (Figures 1 and 2) and a heavy incidence of white/yellow speckling showing through fruit surfaces (Figure 3). Decays included sour rot (*Geotrichum candidum*) (Figures 4 and 5), Rhizopus rot (*Rhizopus stolonifer*) (Figure 6), black mold rot (*Alternaria alternata*) (Figure 7), and likely a little bacterial soft rot (*Erwinia carotovora*) (Figure 8). Review of all reports and photos implicated excessive water in fruit rather than air

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temperatures as the primary predisposition. Excessive water in fruit (water congestion) is possible at virtually any time of the season and can appear at times of cold as well as warm field temperatures (see discussion below).

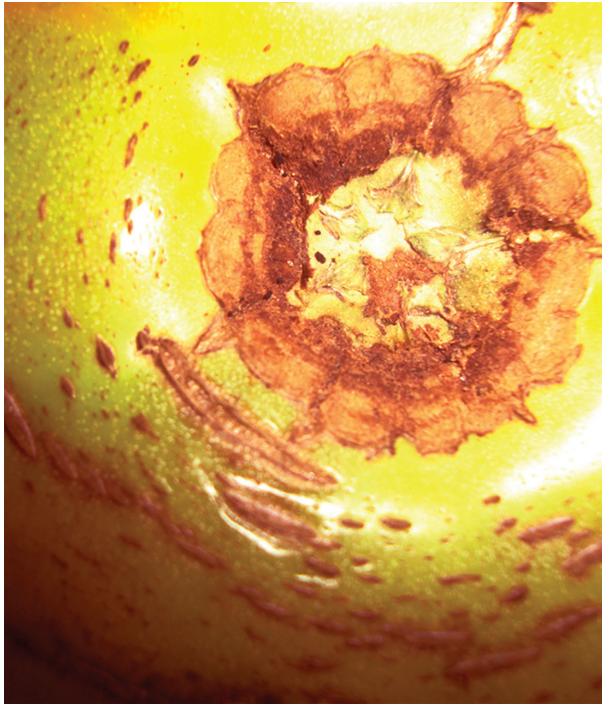


Figure 1. Cuticle cracks partially filled with corky tissues.
Credits: Sharon Bartz

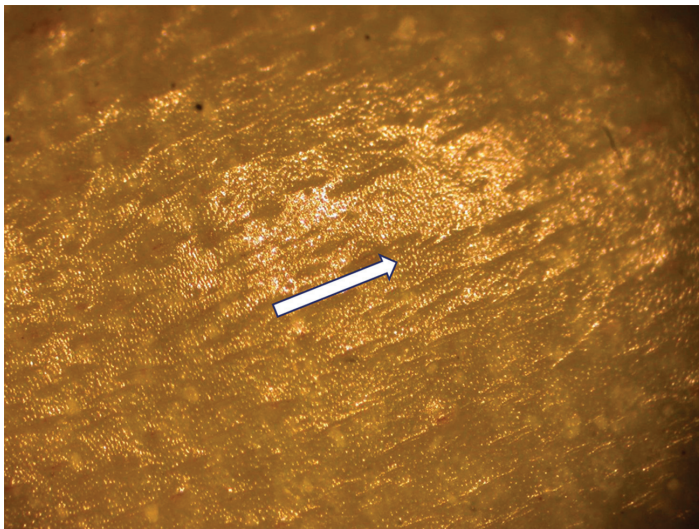


Figure 2. A magnification of cuticle cracks, which roughen fruit surfaces and provide entry points for decay pathogens.
Credits: Deborah Spiceland



Figure 3. Heavy speckling under fruit surfaces led to rejection of tomato shipment upon arrival. These speckles do not disappear as fruit age.

Credits: D. Horner, USDA

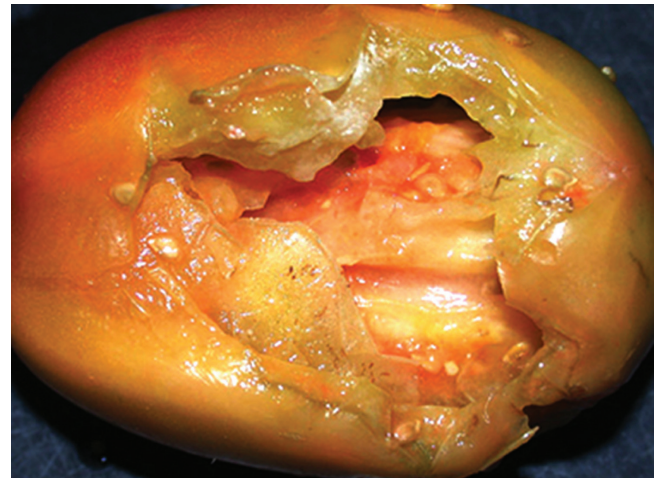


Figure 4. Sour rot in a Roma tomato destroyed the contents of the locular cavity.

Credits: M. J. Mahovic



Figure 5. Upon exposure to air, lesions on standard round tomatoes become covered with white mycelia of the sour rot pathogen, *Geotrichum candidum*.

Credits: M. J. Mahovic

Defects observed on tomatoes produced at a time of cooler/warmer field temperatures

Defects commonly observed among winter or summer tomatoes include misshapeness (catfacing and puffiness) because of pollination failures (Figure 9), poor color development, and surface pitting (Figure 10) and surface cracking (see discussion of surface cracks below). Misshapen fruit have been associated with pollination failures occurring during prolonged periods of cold temperatures in the field (Peet 2009). A week of average day/night temperatures of 63°F/50°F during flower development appears sufficient to cause abnormalities, including pollination failures. Puffiness, which is caused by a failure of the locular cavity to be filled with seeds and gel, not only leads to misshapeness (Figure 9) but also fruit that are easily bruised during harvest and handling. Weather responsible for misshapen fruit also favors crack development in fruit surfaces and white/yellow speckles in the fruit pericarp (see discussion of speckles below). Bruises predispose fruit to increased decay, poor internal quality, and poor flavor characteristics (Moretti et al. 1998). Surface pitting and poor color development (Figure 10) provide direct evidence of chilling injury and limit marketability and postharvest life of affected fruit. Chilled fruit are quite susceptible to postharvest decays that aren't normally problems with undamaged fruit (McColloch 1955; McColloch, Cook, and Wright 1968) and are likely to have off flavors and softness (Peet 2009).

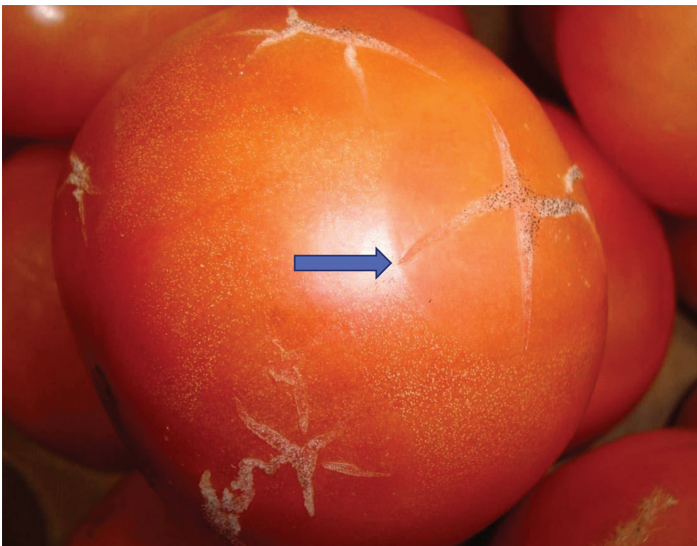


Figure 6. *Rhizopus* lesion on fruit returned to repacker; arrow points to edge of lesion; note the yellow speckling and fungal sporulation. Credits: S. J. Maglio



Figure 7. Black mold rot beginning on fruit shoulders. Credits: J. Bartz



Figure 8. Advanced bacterial soft rot; unlike sour rot, fruit with soft rot completely collapse. Credits: M. J. Mahovic



Figure 9. Angular fruit caused by puffiness (failure of seeds to develop in the locular cavity). Credits: M. T. Elkahky



Figure 10. Poor color development and pitted surface result from chilling injury (also note heavy speckles showing in fruit surfaces). Credits: M. T. Elkahky

Surface cracks: Cracks in surfaces may develop as fruit mature and begin to ripen (Dorais et al. 2004; Emmons and Scott 1997; Peet 2009). Deep cracks—either in circles around stem attachments (called concentric cracking) (Figure 11) or radiating from the stem attachment (called radial cracking) (Figure 12)—occur because of a rapid influx of assimilates (products of photosynthesis) and water into a fruit as its surfaces lose elasticity at ripening onset. This frequently occurs at the end of the spring or summer production seasons when air temperatures increase. The heating effect of rising air temperatures as well as the exposure of maturing fruit to direct sunlight enhances cracking because of the expansion of internal fruit contents, particularly gasses (Peet 2009). Loss of foliar cover from disease and/or mechanical failure of the plant can be responsible for increased fruit exposure to direct sunlight.



Figure 11. Concentric cracking of fruit surface. Credits: M. J. Mahovic

Cuticle cracks are often difficult to detect. Some may be deep enough to enable decay pathogens to infect fruit (Figure 13) or to cause water loss and associated shrivel. Terms used to describe such surface cracks include russetting, rain check, crazing, swell cracking, shrink cracking, hair cracking, or cuticle blotch (Peet 2009). Bakker (1988) noted that incidence of cuticle cracking appears highest early and late in production seasons. Mild cuticle cracks may be detected by observing light reflected off fruit surfaces, particularly at the shoulder region around stem scars. Deeper cuticle cracks enable moisture loss and can be sites for infection by certain decays. Moisture loss is indicated by shrivel, darkening, and other changes in fruit surfaces. Decay initiated in deeper cuticle cracks appears as if the fruit surface were shredded, likely because those surfaces were in contact with fluids released from nearby decaying fruit (Figure 13).



Figure 12. Radial cracking along with speckling and darkened areas in cuticle cracks that result from pathogen attack. Credits: M. J. Mahovic



Figure 13. Sour rot originating at cuticle cracks that were flooded by juice from nearby decaying fruit; note also the heavy white speckling. Credits: S. Jordan

Color defects: Cold field temperatures (chilling injury) and water congestion can cause poor color development. Yellow or orange blotchy colors (Figure 10) are related to cold damage of the fruit's chloroplasts. Cold field temperatures may also lead to the development of white to yellow speckles in the outer pericarp (under epidermis) of a fruit along with cuticle cracks and deeper cracks (Figure 14). Such speckles also have been observed among



Figure 14. Speckles, radial cracks, and cuticle cracks, some of which are being filled with corky tissues.
Credits: Mary Lamberts

fruit developing during warm temperatures (Peet 2009). Speckles are cells containing mineral crystals and should not be confused with pox, fleck, or the feeding of certain insects that rupture fruit cuticles. Den Outer and Van Veenendaal (1988) established that the crystals are mostly calcium oxalate and suggested their formation was a way for the plant to eliminate excessive calcium. Crystals near fruit surfaces are pyramidal and contained within specialized cells called idioblasts. The latter appear as amorphous lumps in the tissues. If the fruit cuticle is removed, these lumps can be pushed with a teasing needle, which confirms their consistency (Figure 15). Profuse speckling on a green fruit along with decay beginning in radial cracks, as shown in Figure 16, has been associated with the presence of sharp raphid (needlelike) crystals in the locular gel near seeds. Raphid crystals are likely to rupture idioblast cells and damage adjacent cells during harvest and handling, particularly during impacts and transit vibration. The result is a “watery mass of mixed cell contents” (Den Outer and Van Veenendaal 1988, 649), which when dried appears like

residues of bruise injury to locular gel (Figure 17). Like cuticle cracking, speckling is more common near the stem attachment (where calcium ion and water enters the fruit). Once formed, mineral crystals are a permanent feature of a fruit. They appear white in green fruit (Figure 16) and yellow in a fully red fruit (Figures 3, 14, and 15). Severe speckling can be a color defect affecting grade standards. During the winter of 2010, severe speckling was responsible for at least one rejection of a shipment of Roma tomatoes (Figure 3) (Bartz, Ritenour, and Elkahky 2010).

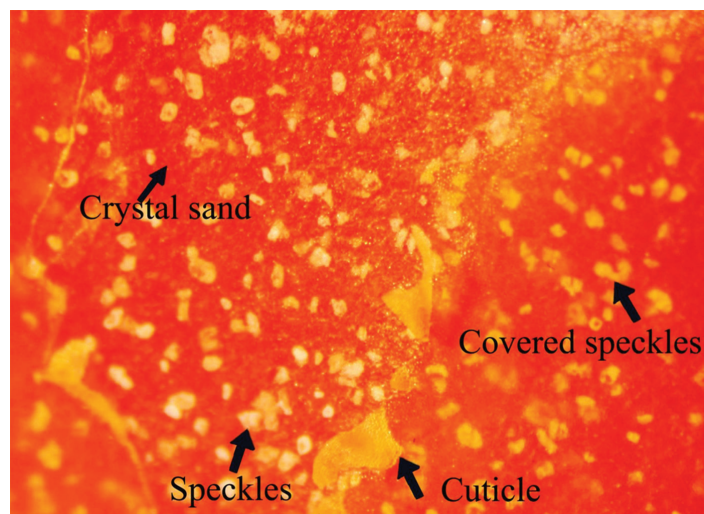


Figure 15. Close-up of larger calcium oxalate crystals (speckles) covered with cuticle or cuticle removed; accumulations of small crystals of oxalate and silicates are called “crystal sand.”
Credits: Sharon Bartz



Figure 16. Profuse “white” speckles in green fruit along with decay beginning in radial cracks.
Credits: M. J. Mahovic

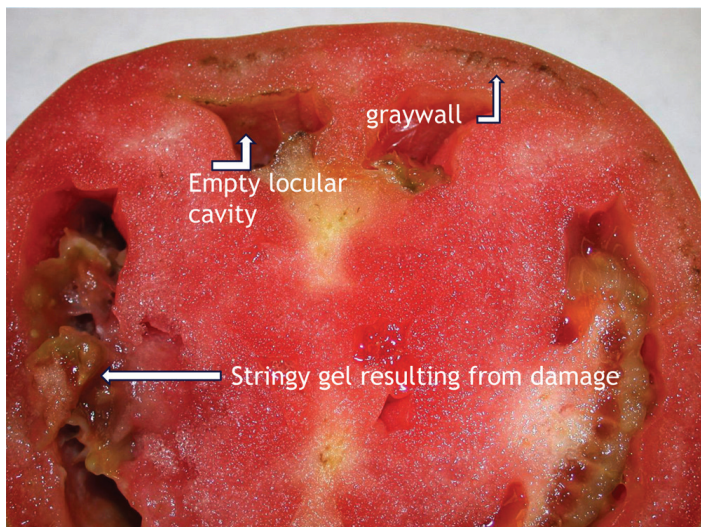


Figure 17. Fruit with gray wall, air in locular cavities (puffiness), and stringy gel resulting from partial drying of damaged locular contents; damage was caused either by raphid crystals in gel or by direct bruise injury.

Credits: M. J. Mahovic

Fruit defects and decay: The defects mentioned above increase the potential for postharvest decays (Den Outer and Van Veenendaal 1988). Rhizopus rot, black mold rot, and sour rot were most numerous among our photos of decaying fruit. Interestingly, the most devastating decay, bacterial soft rot, did not appear often among fruit with cuticle crack/speckling during cool weather, apparently because soft rot is inhibited by cool temperatures. Additionally, storage molds (Figure 18) developed on fruit held under high humidity for 2 weeks. These “molds”



Figure 18. “Storage mold” covering remains of stem and sepals of a heavily speckled fruit.

Credits: M. J. Mahovic

do not directly penetrate the fruit surface but destroy its appearance and marketability. Chilling injury (accumulated hours of exposure to temperatures below about 55°F) predisposes green tomatoes to sour rot (Butler 1960), black mold rot caused by *Alternaria alternata* (McColloch 1955; McColloch, Cook, and Wright 1968), and likely Rhizopus rot. A repacker contacted us concerning decay problems in multiple shipments. Photographs of his decaying fruit (Figure 19) showed signs and symptoms consistent with Rhizopus rot, which likely had infected the fruit prior to arrival. The reported temperature of the arriving shipments (around 50°F) would have inhibited lesion development, but as soon as the repacker warmed his fruit to achieve more color, the pathogen advanced rapidly, leading to major losses within 3–5 days.

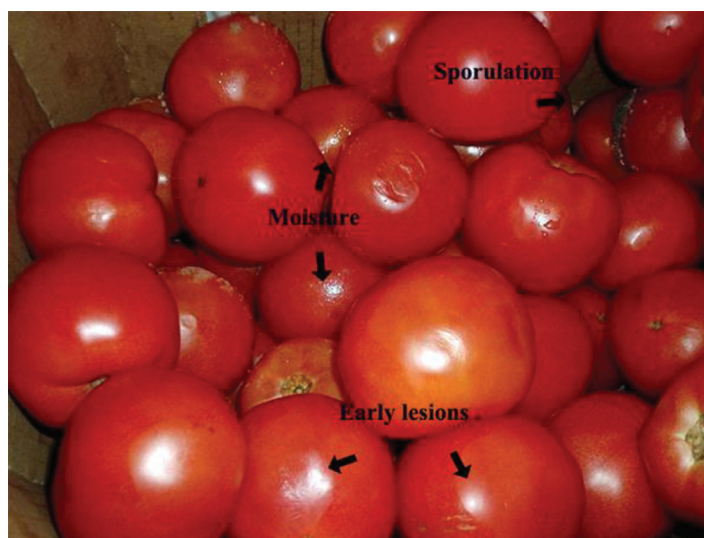


Figure 19. Photograph of distressed fruit submitted by repacker. Credits: S. J. Maglio

Den Outer and Van Veenendaal (1988) indicated reduced postharvest lifetimes could be expected when fruit were intensely speckled and contained raphid mineral crystals. This correlation between intense speckles and a shorter postharvest lifetime would likely be due to increased postharvest decays. At least two Florida growers have reported a situation that likely arose because of internal calcium crystals. Specifically, pink fruit from a typical harvest developed internal molds, whereas green fruit sorted from the same harvest remained relatively clean. When the affected pink fruit were cut open, blackened lesions were found in locular cavities. The pathogen appeared to have grown into the cavity through a defective blossom scar or down vascular strands from the stem scar (Figure 20). If locular gel was reduced to a watery mass during handling, as suggested by Den Outer and Van Veenendaal (1988), then the resulting mixed cell contents could have entered vascular tissues or faulty stylar pores. These contents would

then be available to quiescent infections of *Alternaria alternata*, which is known to attack weakened tissues and to produce a blackened lesion (McColloch, Cook, and Wright 1968). Indeed, *A. alternata* was isolated from our samples of these defective fruit.



Figure 20. Black mold rot growing in a locular cavity; the pathogen appeared to grow up stilar pore (small arrow) or down vascular tissues in stem scar (large arrow) into vacuolar cavity or endocarp, respectively.

Credits: S. Jordan

A consistent correlation in photographs of problem fruit has been that speckling and cuticle cracking occur on the same fruit. Given extensive surface cracking, speckling, and decay shown in this fruit (Figure 21), it was likely water congested at the time of harvest. These fruit, as well as other decaying and defective fruit discussed above, were sampled from packinghouses in various production areas at different times of the year. In each case, we could postulate based on weather records that a heavy influx of water into fruit had likely occurred. Sometimes decay outbreaks occurred when tomatoes were harvested during or after a period of cool field temperatures, where transpiration was greatly reduced, but the soil remained warm and moist. Other times, heavy rainfall occurred after a period of drought when harvest had just begun. Additionally, one outbreak occurred when, at the time of harvest, plant canopies were necrotic because of bacterial diseases, limiting transpiration.

Water congestion (excess water in the plant/fruit): Excess water in fruit is usually not visible but can be inferred from cracks in the fruit surface (as discussed above) and fruit handling characteristics. Fruit congested with water are soft, easily bruised, easily wounded, and have been called “watery fruit” in greenhouse production (Dorais et al. 2002). Water-congested plant tissues are disease prone.



Figure 21. Decay, heavy cuticle cracking, and intense speckling, all on the same, likely water-congested, fruit.

Credits: M. J. Mahovic

Johnson (1947) wrote that water-congested plant tissues “may completely surrender to invasion by a variety of organisms, including saprophytes” (33). Johnson’s studies involved plant leaves, but tomato fruit can also become congested. Bartz, Karuiki, and Jordan (2009) determined that water-congested mature green fruit were susceptible to sour rot, which normally affects only cracked ripe fruit on plants or green fruit that have been injured by chilling (Butler 1960). Excessive water influx into fruit is also related to speckle development.

Sources of water congestion: As discussed above, excessive water can move into fruit whenever transpiration (evaporation of water from plant surfaces) is not sufficient to eliminate water being absorbed by the plant’s roots. This often occurs when a weather event abruptly reduces transpiration and either concomitantly furnishes large amounts of water to the root system or fails to moderate soil temperatures so that water uptake and water loss (transpiration) are balanced. Crops approaching harvest are most likely to be damaged by too much water. Although rainfall can furnish excessive moisture, overirrigation at times when transpiration is reduced can do so as well. Rainfall can also congest wounds on freshly harvested fruit. Fresh wounds attract free water. In laboratory tests, sections of pericarp tissues absorbed water equal to more than 10% of their initial weight within 15–30 minutes (J. A. Bartz, unpublished data). Thus, harvest-related wounds on freshly harvested fruit that are exposed to rainfall will absorb water, and if contamination is present on fruit surfaces, it is likely that contamination will be internalized.

Managing crops and harvests to avoid excessive cuticle cracking, speckling, and decay

Clearly, weather events cannot be controlled. However, certain steps can reduce the impact of those events on the crop. Growing conditions reported to increase speckling include using cultivars with resistance to blossom end rot and applying fertilizers with high Cl^- (relative to $\text{SO}_4^{=}$ and NO_3^-) and high P, high Ca^{++} , high Ca/K ratios, and higher nitrate, along with a high relative humidity environment (Dorais et al. 2004; Peet 2009). Conversely, speckling can be reduced by using cultivar resistance, increasing the electrical conductivity of the nutrient solution, increasing the K/Ca ratio, increasing Mg, and reducing differences between daytime and nighttime temperatures. While most of these reports were directed at greenhouse production, a field practice we've heard being used in Florida seems exceptionally risky. "Pushing" tomato crops with fertilization and extra irrigation as a crop develops during the first harvest period provides nitrate and water that have been associated with speckling and, potentially, water congestion. Irrigation should be balanced with crop needs and available moisture. When weather fronts move through production fields, irrigation programs should be changed as soon as possible so that crops are not overwatered. If heavy rainfall interrupts a dry spell, harvests should be delayed for several days until fruit appear firm and are not readily bruised during handling. Fruit should not be picked from wet or cold plants but should, to the extent possible, be harvested before weather fronts arrive. If fruit have heavy speckling because of uncontrolled weather events, the harvest and transportation to the packinghouse must be as gentle as possible. Finally, no matter what environment exists in the field, freshly harvested fruit should never be exposed to uncontrolled water, such as rainfall or condensation. Harvest-related wounds and even freshly exposed stem scars can be readily penetrated by water. Uncontrolled water internalizes whatever is suspended in it. Loads of freshly harvested fruit should be covered at all times. If temperature change leads to condensation on freshly harvested fruit, then fan drying should be considered so that fruit temperatures are similar to air temperatures and condensation is prevented or minimized.

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