Susceptibility of Produce to Infiltration from Harvest and Postharvest Water

Infiltration: A Food Safety Risk

Water can be used for many things during fresh produce harvest and postharvest handling, including pre-cooling, rinsing, and washing. When fresh produce is warmer than the water temperature, any air spaces within the produce compress, which creates a vacuum. This vacuum may cause water to be drawn into the produce. The movement of water into the produce is called infiltration (see Image 1).

INFILTRATION DEFINITION:

A physical process where water is drawn into plant tissue: it is caused by a pressure differential or capillary action.

Infiltration is a food safety concern because pathogens in the water or on the exterior of produce can be brought into the flesh of the fruit or vegetable. Pathogen infiltration into fresh produce commodities has resulted in outbreaks and recalls. For example, mangoes have been linked to several *Salmonella* outbreaks, attributed to infiltration from contamination of water used in mango treatment to prevent fruit fly infestation (Ref 9, 10, 11). Infiltration is especially a concern in fresh produce that does not go through a kill step, such as cooking, before consumption.

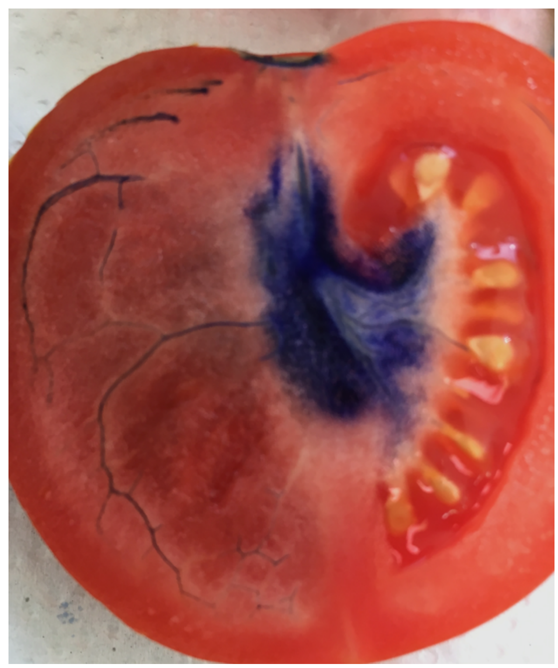

Image 1. *Infiltration of aniline solution into tomato's core. Photo Credit: Strawn Laboratory (Virginia Tech)*

Postharvest water sources include public/municipal water and groundwater, such as well water. The Food Safety Modernization Act (FSMA) Produce Safety Rule (PSR) prohibits the use of surface water sources including rivers, streams, or ponds for harvest and postharvest activities unless the water is treated to meet quality requirements and treatment records are maintained. The FSMA PSR requires that postharvest water (water used during and after harvest) must "be safe and of adequate sanitary quality" for the use, have zero detectable generic *Escherichia coli* in 100 mL, and that the quality be maintained during use (Ref 1). Most third-party audits have similar, or more stringent, water quality requirements.

Risk Factors

To understand what crops are susceptible to infiltration, let's consider why infiltration happens. It can be about pressure (Ref 8). In the same way a balloon shrinks when you go from a warm to a cold space, air gaps in fruits and vegetables shrink when the produce cools; the vacuum formed inside the fresh produce will suck water in through punctures or natural openings on the surface. For vegetables like leafy greens or celery, water can also be sucked into cut ends of stems and leaves through a process called capillary action. If you've ever put celery or a flower into a glass of colored water, you've observed capillary action (see Image 2).

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Image 2*. Capillary action of cut celery in water with food coloring dyes. Photo credit: Tommy Saunders (Produce Safety Alliance).*

Quite a bit of research has gone into understanding these processes, how they affect produce safety and quality, and how they can be managed. Research results describe the potential for *Listeria monocytogenes*, *Salmonella,* and other human pathogens (as well as plant pathogens like *Pectobacterium* and *Erwinia*, a cause of soft rot) to infiltrate produce. A short list of commodities has been studied and shown to be vulnerable to infiltration. It includes tomato (Ref 5), melon (Ref 6), mango (Ref 4), orange (Ref 7), apple (Ref 2) and avocado (Ref 3).

Below is a summary of factors that affect infiltration:

- ***Natural openings***: Produce with openings (e.g., stem scar, calyx) are more susceptible to pathogen infiltration than produce with intact skin, peel, or rind.
    - In mangoes, melons, tomatoes, oranges, and avocados, the stem scar (where the stem attaches to the fruit) is a route for pathogen entrance.
    - In apples, the blossom end (i.e., calyx) allows infiltration.

- ***Damage and injury:*** Wounds and damaged surfaces can be points of infiltration into produce, allowing water (and microorganisms) to bypass natural barriers.

- ***Temperature:*** The combination of hot produce and fast cooling (like submersion into a cold-water tank) leads to more vacuum (negative pressure) and infiltration.

- ***Pressure:*** Deeper submersion also creates more pressure and potential for infiltration. The more pressure that's applied, the more infiltration can occur.

- ***Time:*** The longer the produce is submerged in water or subject to temperature differential, the greater the chance of infiltration.

For lettuce and other leafy greens, the harvest cut typically crosses channels that transport nutrients, carbohydrates, and salts between the roots and the leaves (the xylem and the phloem). When harvested greens are submerged in water, they take on water through capillary action. Infiltration is sometimes done on purpose and called "plumping" or "crisping."

If pathogens are in the water, the practice is potentially risky, and care should be taken to manage the potential for pathogens in the water (see strategies, below). For similar reasons, hydrocooling by submersion should only be done if the potential for pathogens in the water is actively managed.

Strategies to Mitigate

Whenever possible, produce growers, packers, re-packers, processors, and retailers, among others, should implement practices to minimize fresh produce submersion in water (especially for products susceptible to infiltration). Examples include using single-pass spray bars, forced-air cooling, or non-submersion hydrocooling methods. If submerging produce is necessary due to quality, buyer, or regulatory reasons, it is important to consider the following strategies to reduce risk of infiltration. These mitigations can be used alone, or in combination, as necessary in the operation:

1. **Quality/condition of produce**: Poor-quality produce, including bruised, damaged, or punctured fruits and vegetables, may have an increased risk of infiltration. Sorting, culling, or grading produce during harvest or at other times before submerging in water can reduce the risk of infiltration by removing susceptible produce.

2. **Use of a sanitizer**: The use of sanitizers in water will reduce and or eliminate pathogens in the water. The use of a sanitizer in recirculated, batch, or reused water systems including dump tanks, flumes, and triple-wash sinks will reduce the likelihood of cross-contamination (see Image 3).

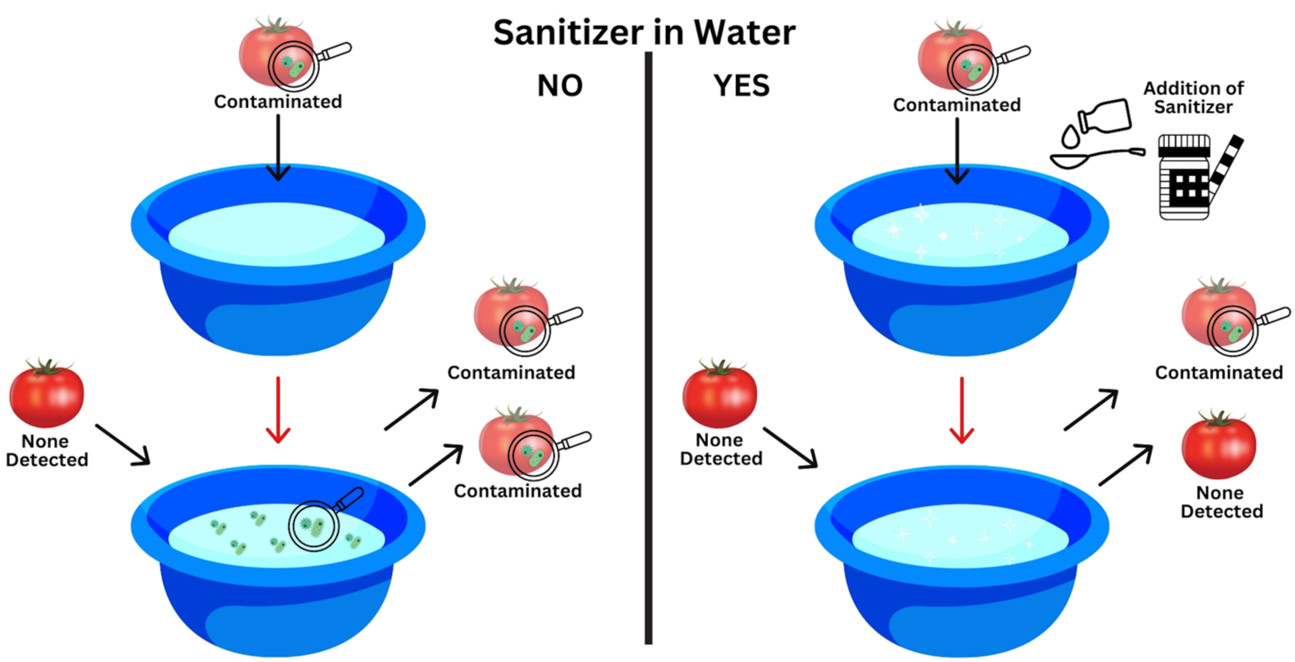

Image 3. *No pathogens in water, no infiltration risk. Visual representation of wash water without and with addition of a sanitizer to show cross-contamination of products.* Photo Credit: Laura Strawn (Virginia Tech).

3. **Temperature differential between the water and produce:** Submerging hot produce into cold water can result in a vacuum that pulls water into the produce – this is why warmer produce in colder water increases risk of infiltration. Submersion of cold produce into warm water does not create the same risk. Monitoring and minimizing temperature differentials between produce and water during harvest and postharvest practices (especially during any submersion activity) are key to reducing infiltration risks. Practices that may reduce the temperature differential include timing of harvest to minimize field heat, non-immersive hydrocooling or otherwise pre-cooling produce, holding and storing harvested produce in shade (not sun), and pre-warming water.

4. **Depth of immersion**: Produce stacked or overloaded into postharvest water systems impact infiltration – the deeper the submersion, the stronger the water pressure, and the more potential for infiltration. A single layer of produce in wash water can minimize the pressure by avoiding produce stacking and deep immersion of produce in water (see Image 4).

5. **Contact time between produce and water:** Longer contact times with water will amplify the effects of temperature and pressure differentials on pathogen infiltration into submerged produce. Practices that reduce the effect of contact time include not leaving produce in harvest and postharvest water systems (e.g., flumes, dump tanks, or sinks) for extended periods, like during breaks.

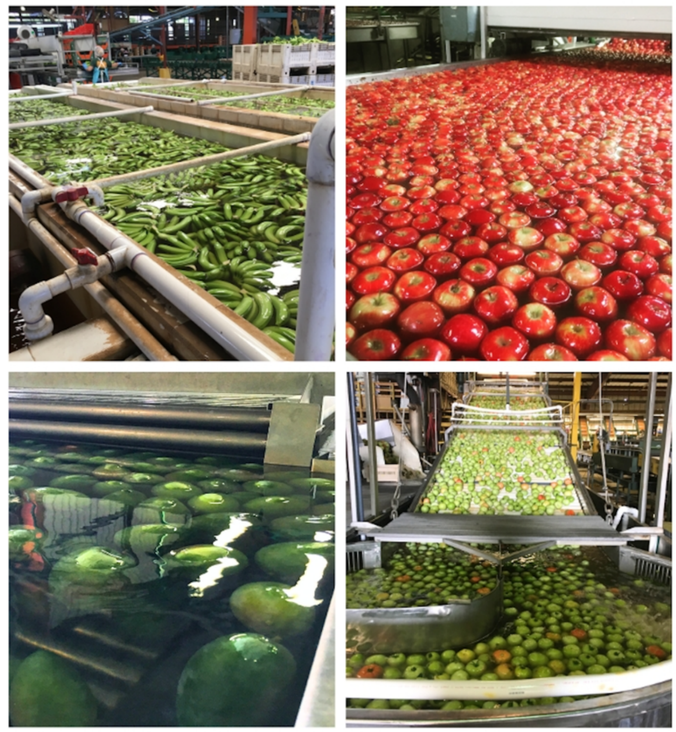

Image 4. *Use of a monolayer to reduce the risk of infiltration by minimizing depth of product in water, reducing the pressure differential. Photo Credit: Laura Strawn (Virginia Tech) and Michelle Danyluk (University of Florida).*

Example questions to use when considering the risk of infiltration in operations:

1. **Quality/condition of produce:** Does the operation have a practice in place (hand sorting, optical sorting) to sort out produce with bruises or punctures and divert that to waste or processing where there is a kill step? If there is, the risk to produce safety is lower.

2. **Use of a sanitizer:** Does the packer treat water used in postharvest with a sanitizer? Is the sanitizer appropriately used and monitored? Sanitizer application that is known to be effective against human pathogens and used according to the EPA label with appropriate monitoring lowers the risk.

3. **Temperature differential between the water and produce (understanding it may vary based on variety for some types of produce):** What is the temperature of the produce when it is submerged in water postharvest (i.e., does it come straight from cold storage, or from the field? If it's the latter, what are the typical environmental conditions during harvest)? What is the temperature of the water when the produce comes into contact with it? Is the temperature monitored? If the packer submerges cooled produce in water that is warmer than the produce, risks are lower.

4. **Depth of immersion:** Is the produce stacked or overloaded into a postharvest water system, or loaded in one layer? Managing the flow of produce to result in a single floating layer is less risky.

5. **Contact time between produce and water:** Is the produce fully submerged in the water, or is water applied in another way? Is the water recirculated? Water application using a spray bar is less risky than submersion. Recirculated water needs to meet FSMA PSR requirements (monitoring, change schedule, etc.). If produce is fully submerged, what is the duration of submersion? Longer submersion in water increases infiltration risk.

Things operations can do to minimize risks:

- Produce that is wounded, bruised, punctured, or has natural openings like cuts is more susceptible to infiltration. Employees should be trained to not harvest damaged produce.

- Water quality is key. Maintaining water that is safe and of adequate sanitary quality will minimize the risks that infiltration poses. The FSMA PSR requirement is that water must have no detectable generic *E. coli* in 100 mL, and quality must be maintained (Ref 1). Third-party audits or other food safety programs also set standards for water quality.

- Use a sanitizer to maintain water quality. By preventing pathogen survival in the water, you are minimizing produce safety risks associated with infiltration.

- Larger temperature differentials, where water is cooler and produce temperature is warmer, can lead to more infiltration (negative temperature differential). Minimize temperature differentials by harvesting at a different time of day, cooling before submission, or avoiding submersion altogether.

- Longer duration of produce submersion in water can lead to more infiltration. Employees should be trained to clear dump tanks before taking breaks.

- Produce submerged deeper into water is subjected to more pressure, which can cause higher infiltration rates. Employees should be trained to not overload dump tanks and to pace how loads enter the dump and float tanks to allow for a single layer of produce.

- Sometimes produce, like leafy greens or tomatoes, are encouraged to take up water during practices like crisping or plumping. Be sure all water used for these activities is free of pathogens.

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