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Hort Innovation CITRUS FUND

Citrus microbial food safety

A targeted practical resource for citrus growers, packers and supply chain participants

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Cover photo: oranges on post-waxing brush rollers. Photo: SP Singh, NSW DPI.

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In 2021–2022, the Australian citrus industry produced 760,076 tonnes of fruit valued at $910.2 million, and almost a third of it was exported to major Asian markets, valued at $451.2 million (Hort Innovation 2023).

The success of citrus export is built on the free trade agreements with importing countries and a clean, green, and safe reputation of the industry. However, the industry needs to be proactive in maintaining the confidence of consumers, regulators and trading partners in the quality and safety of fruit to ensure market access is retained, and new markets are created.

To remain competitive in export markets, the Australian citrus industry must consistently supply safe fruit with the aim of zero product recalls.

Microbial food safety risks to consumers and industry

Due to the inedible peel, citrus fruit poses a relatively low microbial food safety risk to consumers. However, foodborne pathogens on the surface of fresh citrus can be transferred to the edible portion of the fruit or juice, or the hands of the consumer during peeling or cutting.

If pathogens (e.g. *Listeria monocytogenes*) are detected on the citrus fruit surface by regulatory authorities, this could lead to product recalls and reputational losses for the industry, and could be a serious trade risk for export markets.

Like any other food product, citrus fruit could be a carrier of foodborne pathogens capable of causing consumer illness and market failure.

Microbial food safety risks to consumers and industry

A historical perspective

In 1999, a *Salmonella* outbreak affecting 507 consumers in South Australia was linked to unpasteurised orange juice. Based on the investigation reports, the Federal Court ruled that citrus growers who supplied the fruit to the processor had breached their contracts to supply 'safe' fruit, and the liability for the loss and damage was found to rest with the growers (as cited in Rajapakse 2016). The *Salmonella* Typhimurium (phage type 135a) strain involved in the outbreak was traced back to the fruit in the packing shed and, in particular, to the fungicide and wax solutions that were applied to the fruit.

Prevention of this outbreak was possible with certain measures, including using a sanitiser in the wash and fungicide tanks as well as regularly changing the water in the fungicide tank (Rajapakse 2016).

This historical example refreshes the microbial food safety risks posed by fresh produce, including citrus. Similar examples of salmonellosis outbreaks linked to citrus juice products have been reported in other countries (Parish 1998).

It is not only an ethical or moral responsibility, but a legal obligation to supply 'safe' fruit, which is a food product.

Microbial food safety risks to consumers and industry

Microbial risks

Fungal

Penicillium spp.

Alternaria spp.

Bacterial

Salmonella spp.

Listeria monocytogenes

Shiga-toxin *Escherichia coli* (STEC)

Campylobacter spp.

Viral

Noroviruses

Hepatitis A

Parasitic

Cryptosporidium spp.

Cyclospora spp.

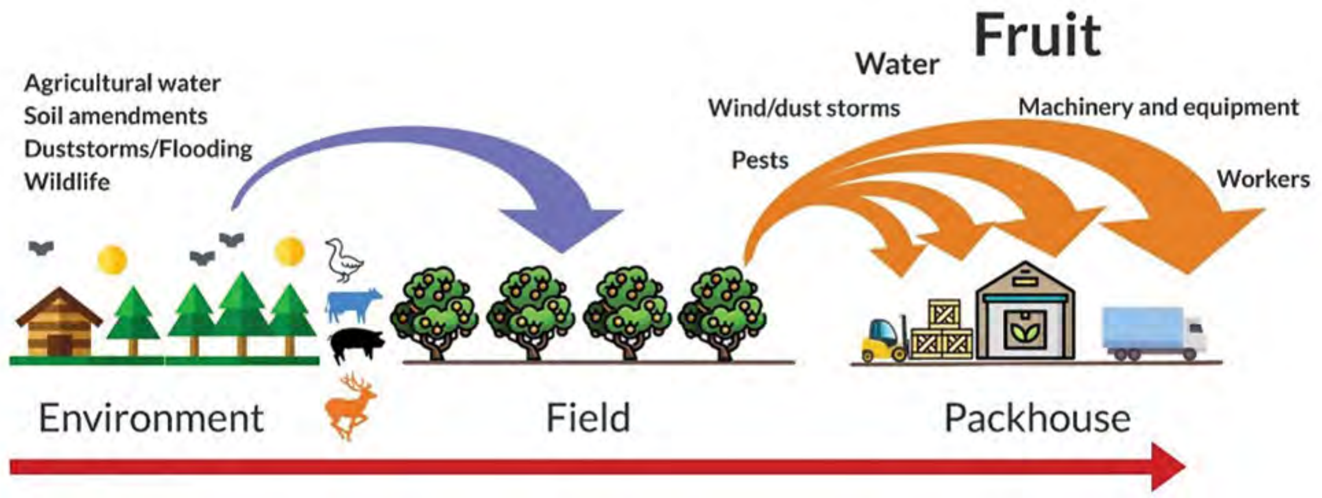
Bacteria, viruses and parasites can cause illness in humans. These microbial pathogens generally originate from animals and humans, and they enter the fruit supply chain during production and postharvest.

Microbial pathogen continuum

Environmental pathogens such as *Listeria monocytogenes*, *Salmonella* spp. and pathogenic *Escherichia coli* are widely prevalent in natural conditions (Strawn et al. 2013).

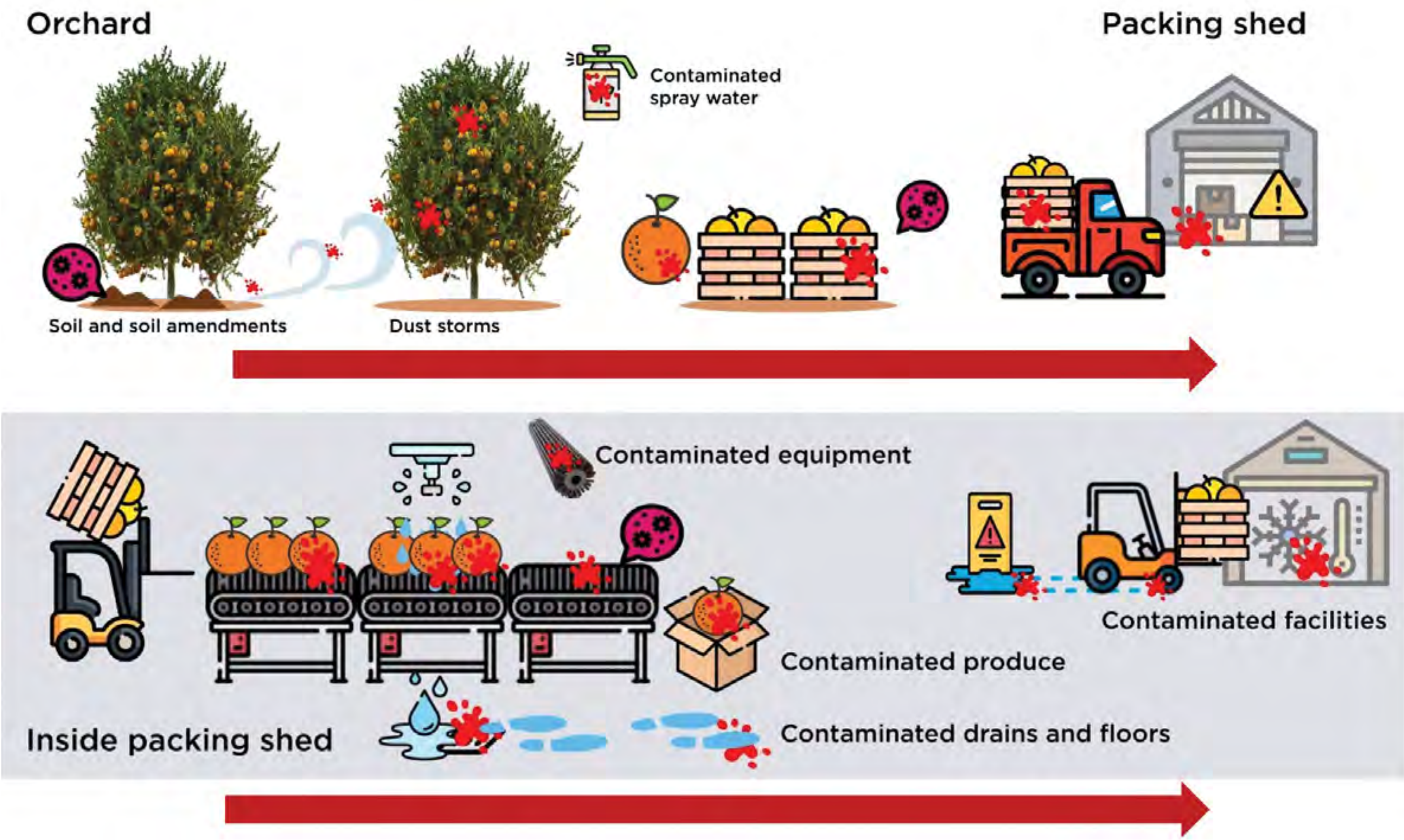
Among these pathogens, *Listeria monocytogenes* has been reported to be the most prevalent in fresh produce production landscapes, particularly in soil and water (Strawn et al. 2013; Weller et al. 2015).

These pathogens can be transferred to fruit through various routes, and their transmission is enhanced by extreme weather conditions such as dust storms, flooding, and heat waves (Singh 2023).



Microbes rule the world; never underestimate the power of microbes.

Microbial pathogen continuum

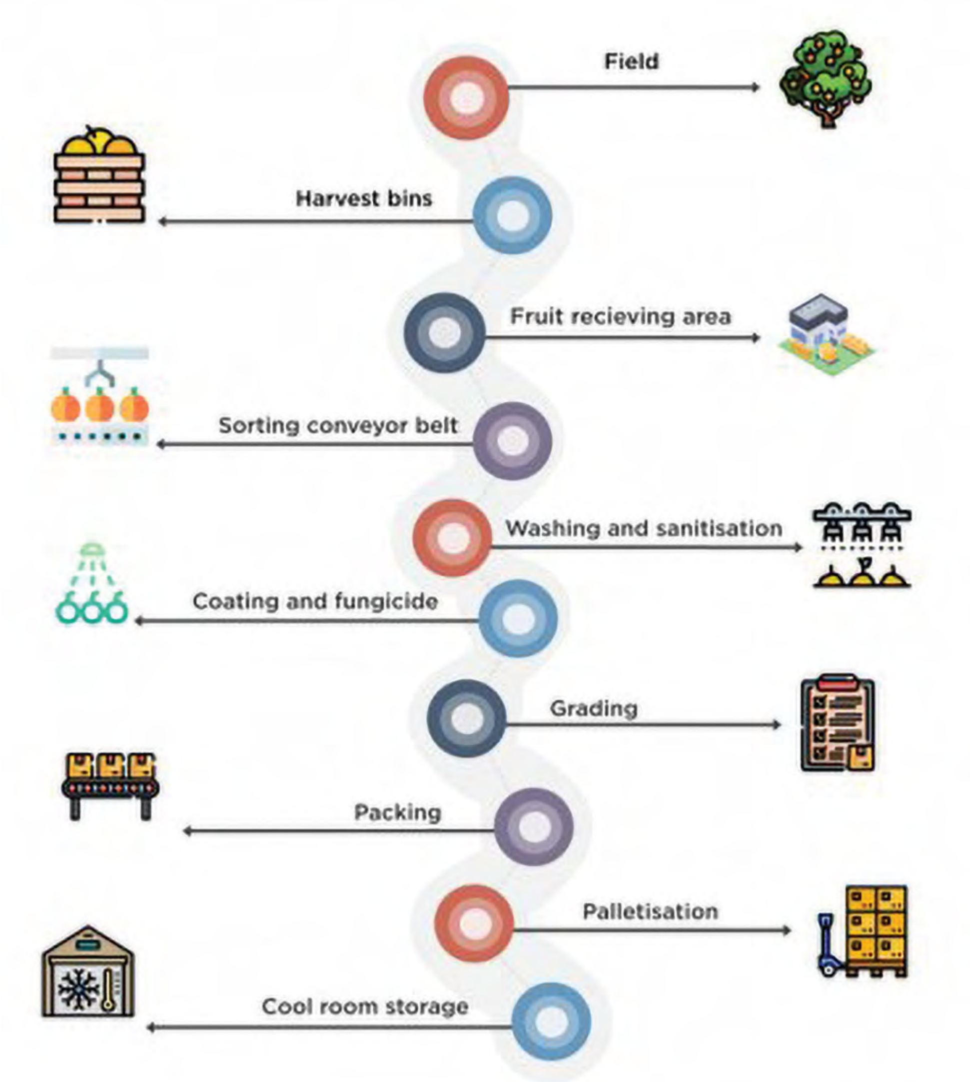


The proposed microbial continuum is based on citrus industry data and evidence, and are validated by whole-genome sequencing tools.

Microbial risk mapping

Our research showed that *Listeria monocytogenes* was the primary environmental pathogen of concern in the supply chain. Shiga-toxin *E. coli* (STEC) was the second most prevalent in soil samples. *Salmonella* was prevalent at very minor levels in environmental samples from packing sheds.

The microbial risk mapping data were based on 2,257 microbiological samples collected from 51 citrus packing sheds, representing over 750 growers across Australia.

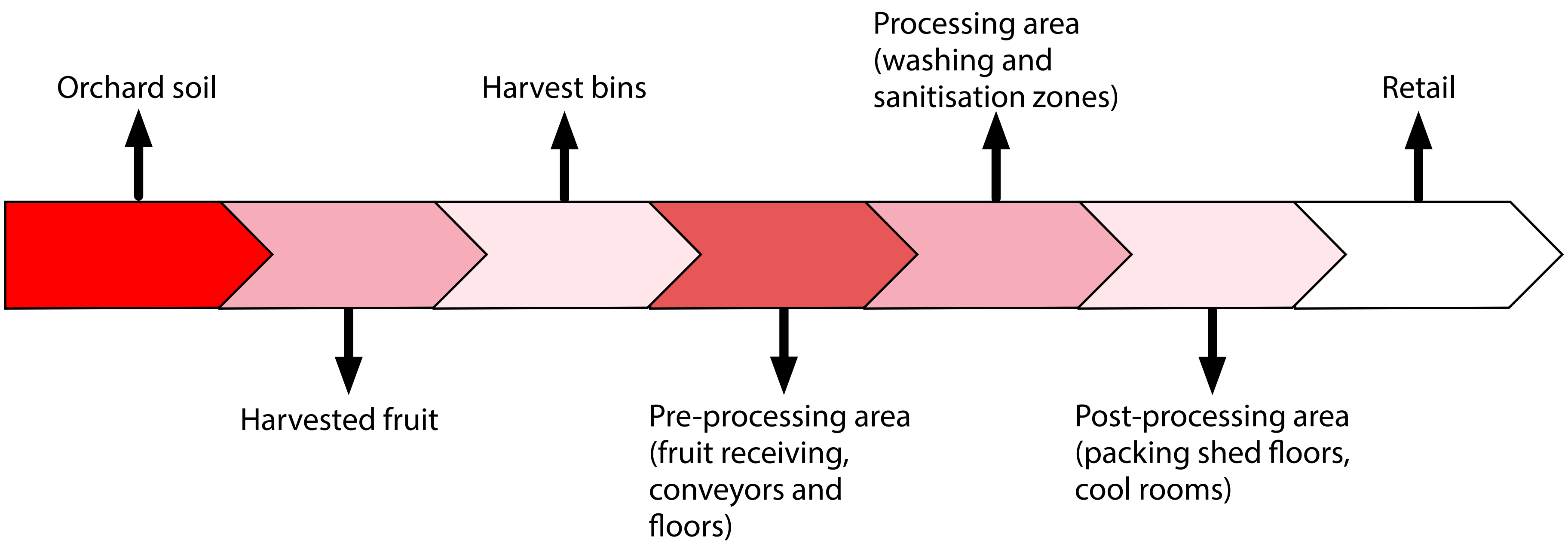


Knowing the nature, amount and location of pathogens is critical to designing and applying food safety interventions.

Microbial risk mapping

Prevalence and distribution of *Listeria monocytogenes* in the citrus supply chain

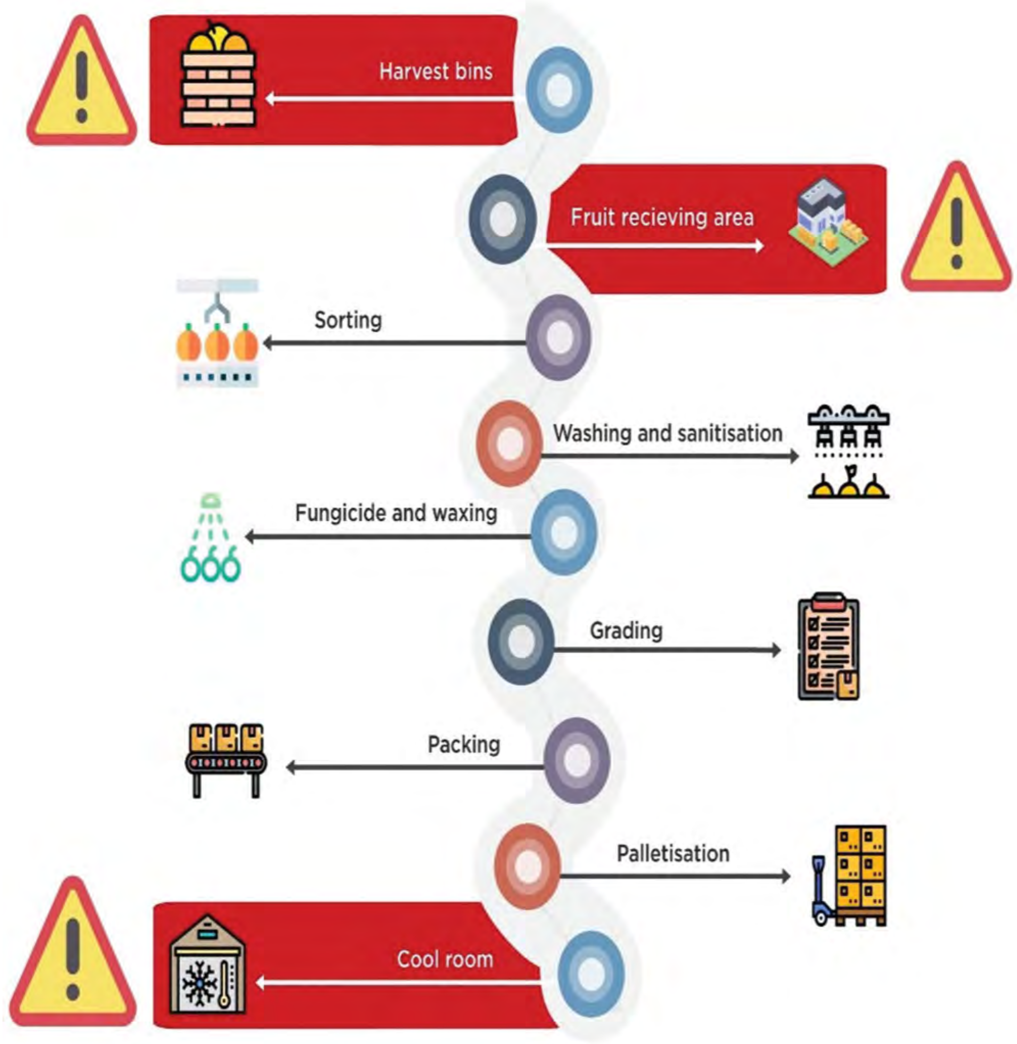
The microbial risk pathway shows the prevalence of *Listeria monocytogenes* (the deeper the red shade, the higher the prevalence) along the supply chain from field production to retail. The darker regions require preventative control interventions by citrus growers and packers.



Microbial risk mapping

The following hotspots have been identified for microbial contamination and cross-contamination:

- harvest bins
- fruit receiving area
- brush rollers
- wash water tanks/flumes
- fungicide and waxing solutions
- cool rooms



Allocating cleaning and sanitisation resources to hotspots will provide long-term benefits to citrus packers.

Industry practice gaps identified

- Adopt dust-suppression agronomic practices in orchards.
- Avoid using raw animal manure in citrus orchards.
- Improve harvest practices and harvest bin hygiene.
- Clean and sanitise the fruit receiving area in packing sheds.
- Maintain adequate levels of sanitisers in wash water and dump tanks.
- Adopt objective measures of fungicide solution change frequency.
- Automate sanitiser dosing and monitoring in postharvest water systems.
- Verify fruit postharvest sanitisation using digital tools.
- Enhance knowledge about the postharvest treatment interactions.
- Improve packing shed cleaning and sanitisation protocols.
- Develop and implement environmental monitoring programs in packing sheds.

Find and mind the gaps; it will end the crisis before it begins.

Best practice guidance

Objectives

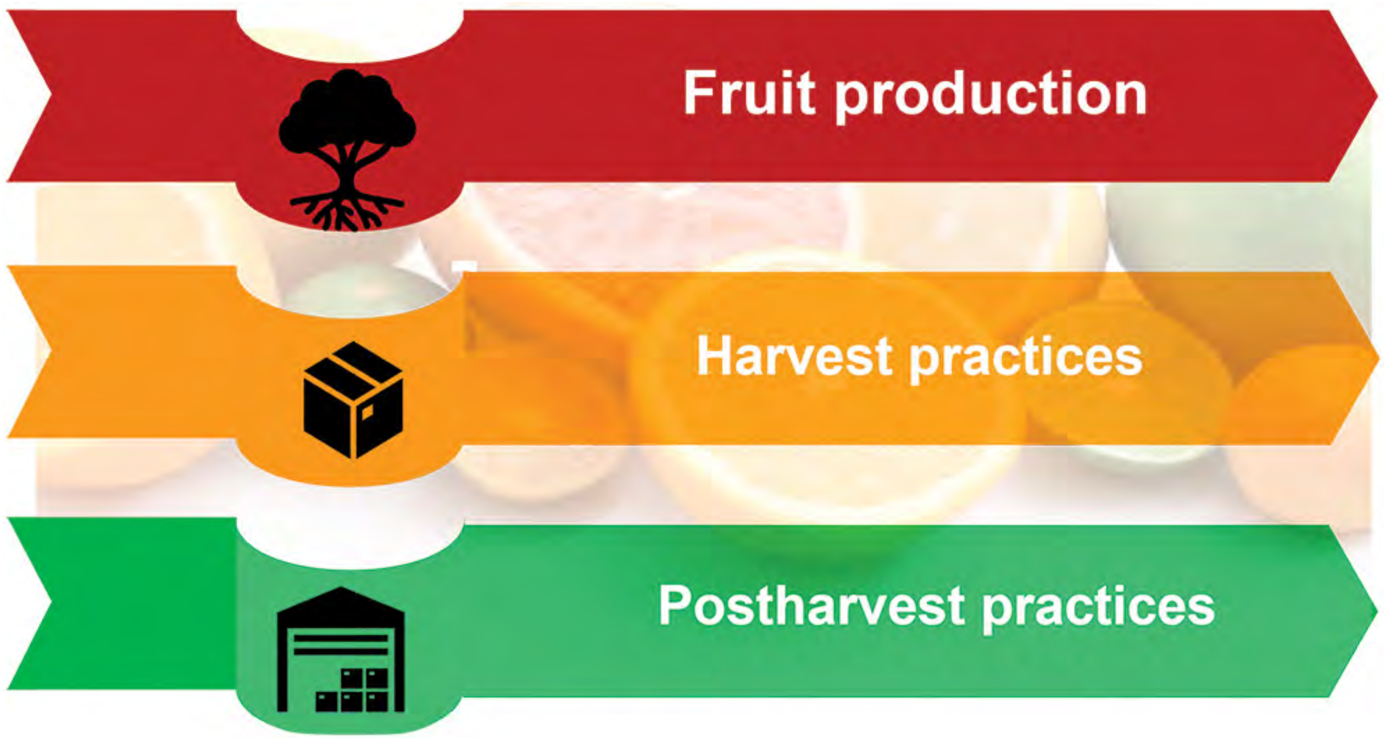
The objectives of this guide are to:

- Raise awareness of microbial food safety risks associated with citrus fruit production and supply.
- Enable benchmarking of food safety practices in citrus production and postharvest handling, allowing identification and filling of potential practice gaps.
- Enhance understanding of the nature and magnitude of microbial food safety risks associated with citrus production, harvest and postharvest operations.
- Enhance food safety skills and knowledge of citrus growers, packers and other supply chain participants.

Scope and contents

Food safety schemes (e.g. Freshcare, SQF) are widely adopted in the industry. Therefore, the information provided here is specifically targeted at overcoming the gaps in food safety practices, and is supplementary to the existing schemes.

The guidance is focused on 3 main areas:



Food safety certification is based on the snapshot of evidence provided on the day of the audit, but good food safety practices should be part of everyday culture.

Literature review

- *Listeria monocytogenes* has been reported in citrus packing sheds in California (Suslow et al. 2019). The prevalence and distribution patterns found in California were similar to Australian conditions.
- *Listeria monocytogenes* attach to the citrus fruit surface more strongly than *Salmonella* and *E. coli* O157:H7, making it harder to kill during fruit washing and sanitisation processes (Martínez-Gonzáles et al. 2011).
- Postharvest washing and sanitisation treatments are known to be the hotspot for cross-contamination of fruit if the sanitisation of wash water, fungicides and waxes are not maintained (Kanetis et al. 2008; Harris 2019; Adaskaveg et al. 2021; Sheng et al. 2023).
- Bacterial pathogens can survive in waxing solutions for extended periods and also on fruit surfaces (Sheng et al. 2023).

Fruit production

Listeria monocytogenes is ubiquitously present in soils and is shed by cattle and sheep suffering from listeriosis infection. It is also found in contaminated irrigation water (Weller et al. 2015). Our research showed that most *Listeria* strains were isolated from orchard soils under the tree canopy, approximately 300 mm away from the tree trunk.

Listeria's persistence and survival varied from orchard to orchard, presumably influenced by the following factors:

- organic soil amendments
- irrigation water quality
- leaf litter under the tree
- high soil moisture throughout the year
- no exposure to UV under the tree.

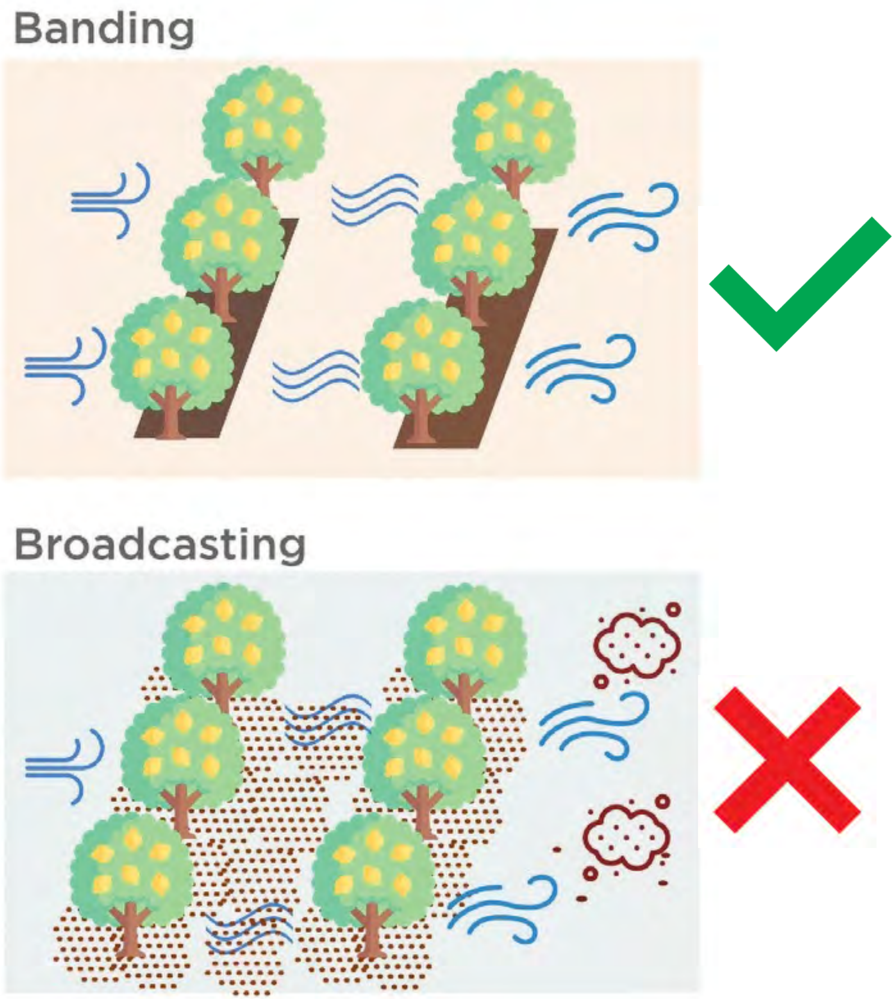
Do not apply raw, untreated or partially composted animal manure in citrus orchards.

Fruit production

Using organic amendments to help soil health in orchards is common.

Composts should be sourced with a certification of the composts' compliance with Australian Standards. The timing (e.g. after fruit harvest) and method of applying (e.g. banding or broadcasting) organic amendments can be important for mitigating microbial food safety risks.

Most growers are aware of microbial contamination risks linked to raw animal manure. However, knowledge of the transfer routes of microbial pathogens from the environment to fruit is uncommon.



The timing of compost application should be restricted to after fruit harvest, and the band application method should be adopted instead of broadcasting.

Fruit production

Drip irrigation is the most common method used in citrus production. As this method applies water to the soil and not the plant, it minimises the direct microbial contamination of fruit by water.

Contaminated irrigation water can introduce microbial pathogens to orchard soil. This has been reported as one of the major carriers of *Listeria monocytogenes* in fresh produce production in the field (Weller et al. 2015).

Using contaminated water for chemical spray applications, especially before fruit harvest, could contaminate fruit. In addition to the microbial risk, water sources contaminated with blue-green algae (BGA) could contain BGA toxins, which could be transferred to the fruit.

The persistence and diffusion of BGA toxins on and into citrus fruit are currently unknown.

Monitor the microbiological quality of irrigation and chemical spray water, especially 1–4 weeks before fruit harvest. Know the water source, and potential contamination upstream.

Fruit production

Agronomic practices (e.g. inter-row management) to manage the inter-row sod culture will help suppress dust. These are recommended to minimise the transfer of *Listeria monocytogenes* from soil to fruit.

Windbreaks and orchard netting could help minimise dust on the fruit surface, reducing the microbial load on fruit, among other benefits in crop production.

Perennial windbreaks can reduce the dust on fruit (e.g. from dust storms) associated with microbial contamination.

Fruit production

Photo: Shane Burgess, NSW DPI

Dust storms are powerful vehicles for microbial pathogen dispersal and large-scale contamination of food production and water systems.

Fruit production

Coexistence of citrus orchards and livestock

The coexistence of citrus and livestock industries is common in some regions. Livestock operations (e.g. cattle feedlot, poultry, piggery, dairy) could be a primary contributor to the microbial contamination of surface water sources. They can also be a source of the long-distance dispersal of pathogens with dust storms.

Using inexpensive animal by-products from intensive operations could lead to microbial contamination of fruit production fields and water sources.

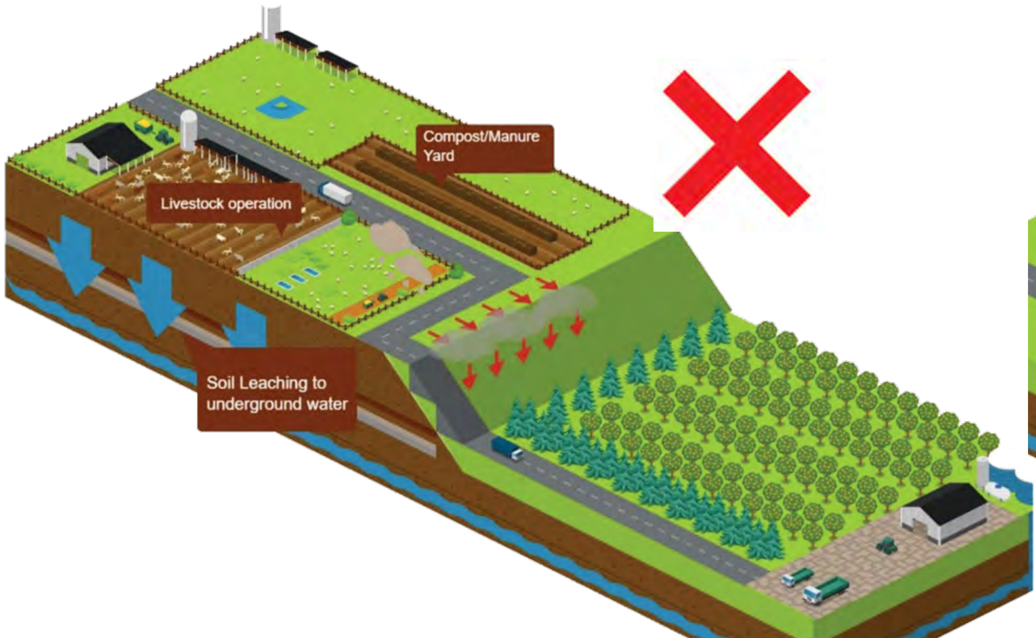
Using buffer zones, managing run-off, planting windbreaks and monitoring water sources are practical and effective ways to mitigate microbial risks.

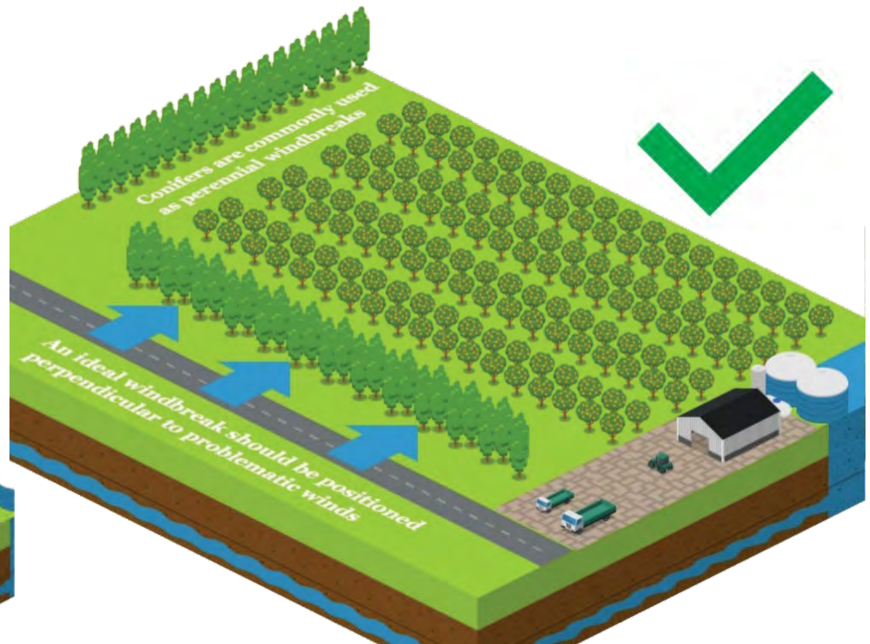
Fruit production

Growers commonly report wildlife incursion in the citrus orchards along with the awareness of the risks these animals pose to microbial food safety.

Growers undertake measures to minimise the wildlife incursion into their farms and water sources. Fencing and barriers are the most animal-friendly measures to restrict wildlife access to production fields.

Natural disasters such as floods and bushfires can displace wildlife towards production fields and water sources. Consider the effects these conditions can have on your production fields.

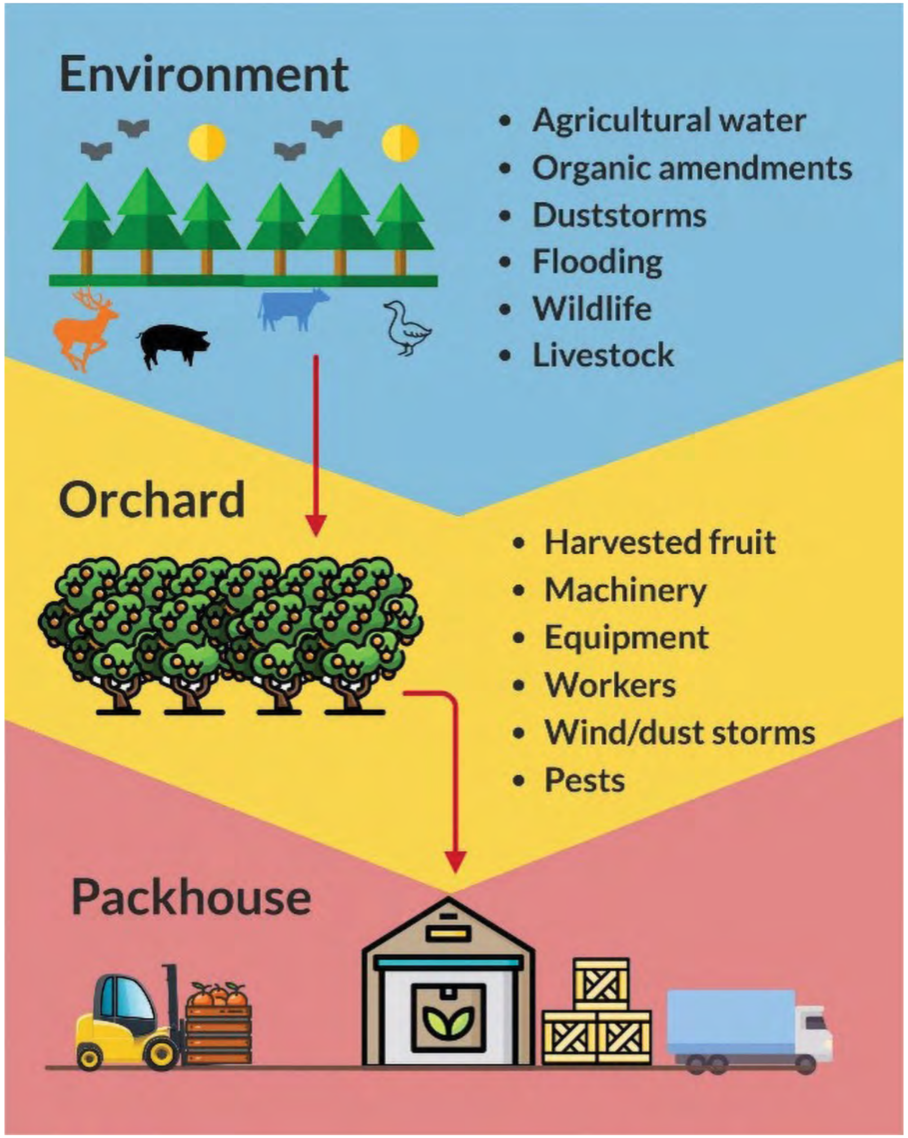




Assess and manage the microbial food safety risks posed by wildlife in your region. Consider the microbial risks associated with neighbourhood livestock operations and upstream water contamination sources.

Harvest

Potential vectors and pathogen transfer routes into orchards and packing sheds



Harvest

Avoid placing harvest bins on the ground during fruit harvest as this will cause soil and debris to stick to the bins.

Harvest

Once harvest bins are lifted from the orchard floor and stacked during fruit transport to the packing sheds or for temporary fruit storage, the soil and mud get transferred with them, causing widespread soiling of fruit and harvest bins.

Since environmental pathogens such as *Listeria monocytogenes* live in soil; this is potentially the main reason for microbial contamination of harvest bins and fruit during harvesting operations. Having contaminated soil on harvest bins was the major food safety practice gap during harvesting operations.

Stacking muddy harvest bins transfers soil and organic matter to the inside of the bins, soiling the fruit.

Harvest

Trailer mounting is strongly recommended to prevent harvest bins from contacting the ground.

Harvest

Cleaning and sanitisation are two separate steps. Cleaning involves using food-grade detergents to remove excessive dirt and extraneous matter from the bins. Sanitisation involves disinfecting the bins with a food-grade sanitiser.

Some citrus packers have installed and started using automated cleaning and sanitisation systems for harvest bins. Care needs to be taken when using this equipment that it does not spread pathogens to sensitive areas around the packing shed or other equipment.

Clean and sanitise harvest bins after each use. Use separate bins for handling fruit before and after processing.

Postharvest

Postharvest fungicide drenching

Pre-wash drenching is a common practice to minimise fungal rots in the supply chain. Drenching uses a large quantity of fungicide in recirculation mode to drench citrus fruit in harvest bins. Since this is the first wash/drench step, there is a significant organic load in the drench solutions.

Postharvest fungicide drenching was identified as the major risk of cross-contamination of fruit with bacterial pathogens.

Postharvest

Harvest bins, which are generally placed on the ground during fruit harvest, introduce more organic matter into the drench solution, potentially affecting the fungicide efficacy and transferring bacterial pathogens into the drench solution.

Fungicide solutions generally do not have bactericidal effects, and bacterial pathogens such as *Salmonella* and *Listeria monocytogenes* can survive in most fungicide solutions (Harris 2019; Adaskaveg et al. 2021).

Foodborne bacterial pathogens can survive in most fungicide solutions.

Postharvest

How often the fungicide drench solution should be changed will depend on the organic matter load anticipated during each lot of harvest and the volume of fruit treated.

To minimise cross-contamination risks due to bacterial pathogens, sanitisers should be used to sanitise fungicide solutions, provided they are compatible with each other.

Mixing fungicides and sanitisers is not recommended unless the manufacturers have suggested their compatibility for this use.

Determine the frequency of fungicide solution change based on the organic load accumulated and the volume of fruit treated rather than time-bound.

Postharvest

A citrus packer in the Murray region uses a two-step high-volume drenching system in which fruit first receives a sanitiser drench (Step 1) followed by a fungicide drench (Step 2). This is a best practice example to mitigate cross-contamination risks during fungicide drenching operations.

This two-step high-volume drenching operation will minimise cross-contamination risks and maximise the efficacy of both sanitisers and fungicides.

Postharvest

Cool chain

Following postharvest fungicide drenching, fruit are generally held in cool rooms until further processing. If degreening is required, the fruit are held in degreening rooms maintained at the required temperature, humidity and ethylene conditions.

Occasionally, fruit in harvest bins, before and after drenching, were observed to be stored under ambient conditions (inside and outside the sheds), which is not ideal because it adversely affects the storage potential and microbial food safety.

Maintaining a cool chain after harvest is critical to maximise food safety, storage and transport potential of fruit with minimal quality and fungal decay.

Postharvest

Fruit receiving area

The fruit receiving area in the packing shed is the gateway for fruit (and environmental pathogens) to enter the processing facility. The harvested fruit comes with a significant amount of organic matter and debris from the field.

Clean and sanitise the fruit receiving area after each shift so the environmental pathogen transfer continuum is interrupted.

Postharvest

When bin tip platforms are covered with porous padding material to minimise impact damage to fruit, it provides harbourage sites to pathogens such as *Listeria monocytogenes*.

Packing line equipment should be regularly maintained to replace damaged surfaces.

Postharvest

Some packers neglect the packing line area for regular cleaning and sanitisation due to labour, water and chemical costs. As a result, more *Listeria monocytogenes* detections were recorded in the fruit receiving areas compared with other sampling locations.

As most citrus packing facilities are not designed with proper drainage for regular cleaning, this is a challenging aspect. Regular wet conditions, along with high organic load, are ideal for pathogen survival and growth.

The fruit receiving area was identified as the weakest link in the food safety management chain.

Postharvest

Fruit dumping

Dry dumping is a common industry practice that minimises microbial cross-contamination risks posed by water flumes. The citrus packers who use wet dumping must use a sanitiser in the dump tank or flumes. However, maintaining an optimum sanitiser concentration in large quantities of water could be a challenge. Water should be changed frequently, especially with high organic loads.

Dry dumping with careful unloading of fruit onto the conveyor belt is relatively lower risk for microbial cross-contamination than wet dumping in large volumes of water or water flumes.

Postharvest

The wet dumping process is believed to reduce the impact damage to fruit during dumping. On the other hand, dry dumping could cause minor injuries and cracks in the fruit, leading to potential pathways for bacterial and fungal pathogens to enter the fruit during subsequent processing steps. Postharvest physical injuries cause higher levels of fruit breakdown in the supply chain.

Wet dumping involving immersion of harvest bins in the water tank will greatly increase the risk of cross-contamination.

If harvest bins are placed on the ground in orchards, they are highly likely to transfer significant loads of soil and organic matter to the dump tank or water flume.

Maintain optimum levels of sanitisers in dump tanks and water flumes to prevent cross-contamination.

Harvest bins should be trailer-mounted if they are to be immersed in the water tank during fruit dumping.

Postharvest

Pre-wash sorting

Pre-wash sorting is not a common practice. Damaged and rotten fruit also go through washing and sanitisation processes, leading to an increased microbial burden on the packing system and wasted resources used in processing.

Packing line design and layout should consider the provision for deploying workers to sort the fruit before the washing and sanitisation zones.

Sorting out rotten and damaged fruit before washing and sanitising is a cost-effective strategy to minimise mould spore load in the fungicide tanks and packing shed. It will also improve the food safety outcomes.

Postharvest

Postharvest water

Postharvest water is an important element for the microbial food safety of citrus fruit.

Citrus packers use a variety of postharvest water sources. Based on the practice data, it is estimated that ~51% of citrus packers use surface water (river, creek, channel, dam, rainwater) for postharvest operations, while the use of town water and groundwater is 41% and 10%, respectively.

Drinking quality water is recommended for postharvest applications in citrus packing sheds.

Postharvest

Surface water from various sources (rivers, creeks, channels, dams and rainwater harvesting) is the most common for citrus packers in remote locations. The microbiological quality of surface water changes dramatically, depending on the season and weather.

More than half of the citrus packers who use surface water have installed water filtration and treatment systems to improve water quality for postharvest use. Town water, which is considered the safest, is used in packing operations (41%) located in larger towns.

Using water filtration and treatment systems are recommended in packing operations that use surface water sources.

Postharvest

Brushing and washing

Flatbed brushes are most commonly used, along with spray bar washing. Ideally, all brush rollers should be under the sanitised wash water for self-cleaning purposes. Brush hygiene is important to minimise cross-contamination risks.

Listeria monocytogenes was detected in several samples collected from brushes in the washing areas. Once brushes get contaminated with bacterial pathogens, they are very difficult to clean and sanitise. Completely replacing the contaminated brush rollers is the practical solution.

All brush rollers should remain under the sanitised wash water and should be cleaned and sanitised at the end of the shift to remove organic matter and debris.

Postharvest

Pre-wash rinsing is recommended to minimise microbial load on recirculatory wash water systems.

Postharvest

Postharvest wash water sanitisers

Recirculating wash water is a common practice. Most postharvest operations recirculate wash water without a filtration step, but the use of sanitisers is common.

Maintaining optimum concentrations of sanitiser and frequent water changes are recommended to minimise cross-contamination risks.

Treat the wash water to drinking quality before it is used/re-used for fruit washing to mitigate microbial contamination risks to the lowest level. Alternatively, a single-use wash water (run-to-waste) system is recommended, but it might not be an environmentally sustainable option.

Postharvest

Peroxyacetic acid (PAA) is the most popular sanitiser used in the industry, followed by calcium hypochlorite, chlorine dioxide and others such as sodium hypochlorite, chloro-bromo dimethylhydantoin, and chlorocyanurates.

Most citrus packers using PAA, chlorine dioxide and chloro-bromo dimethylhydantoin as sanitisers are using automated dosing systems to inject the sanitiser into the wash water. However, many sodium/calcium hypochlorite and chlorocyanurate users manually add sanitisers to wash water tanks.

Postharvest

Each sanitiser has its own merits and limitations due to its highly oxidative nature. It is recommended that the industry should avoid using chlorine-based sanitisers due to their negative impact on the environment.

Using PAA in postharvest wash water is recommended due to its efficacy and low environmental impact. Also, its action is least influenced by the presence of organic matter.

Other options, such as electrolysed water and ozone, should be explored to meet sustainability requirements with minimal environmental impact.

Postharvest

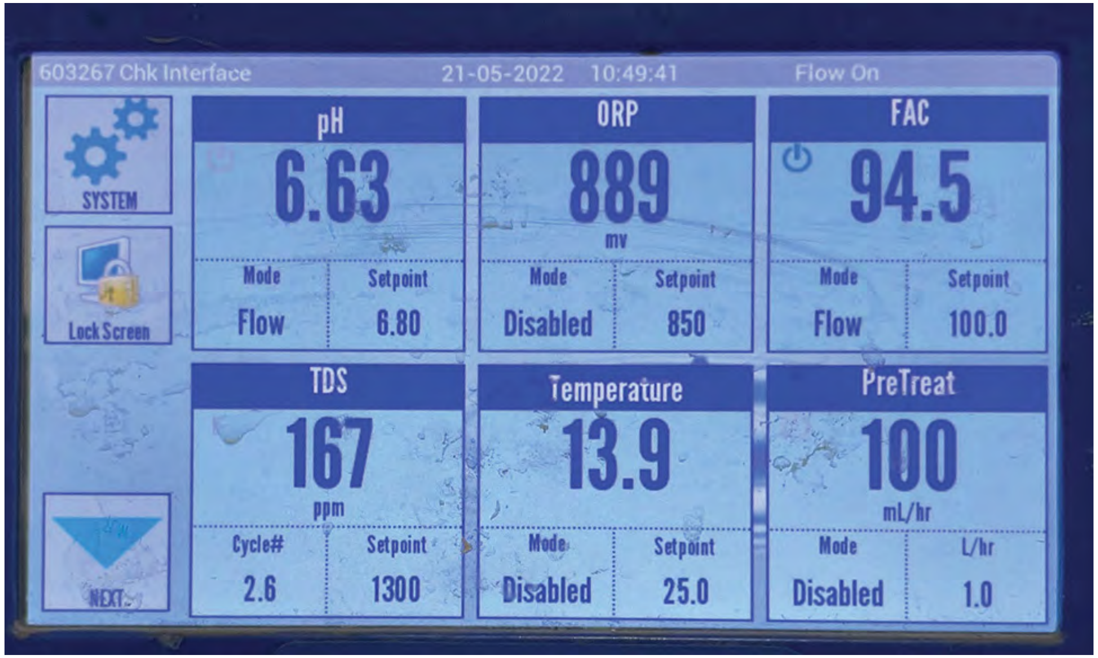
Automated sanitiser dosing and logging are recommended to eliminate human errors. Furthermore, sanitiser concentration should be verified at regular intervals using digital measurement tools.

Using test strips to measure sanitiser concentrations and pH should be avoided due to their limited accuracy.

Automated sanitiser dosing and monitoring systems are highly recommended to remove human errors.

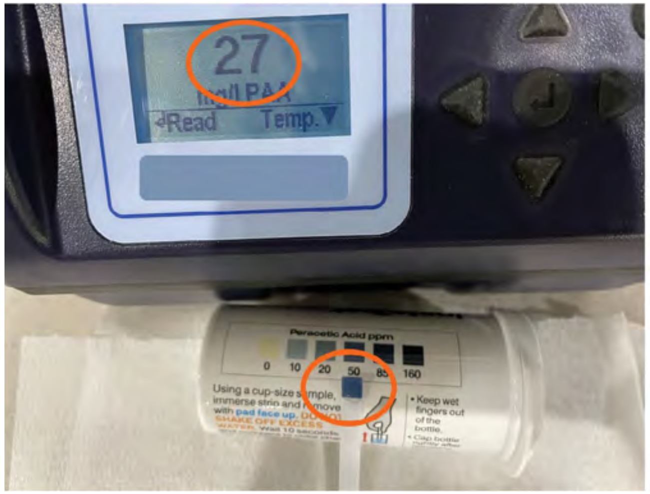
Postharvest

Most operations did not achieve the target sanitiser concentrations and were dependent upon test strip results for verification.



Achieving recommended levels of sanitiser concentrations is critical to mininise microbial food safety risks associated with postharvest wash water.

Postharvest



Peracetic acid

Target concentration: 80 ppm

Actual concentration: 50 ppm (test strip)

27 ppm (digital meter)

Iodine

Target concentration: 2 ppm

Actual concentration: 2 ppm (test strip)

Oxidation potential (ORP) = 620 mV (sub-optimal)

Chlorine-bromine

Target ORP: 500 mV

Actual ORP: 365 mV (sub-optimal)

Achieving target concentrations of sanitisers is critical to the sanitisation process. Sub-optimal sanitiser concentrations and a lack of digital verification of these concentrations are key concerns.

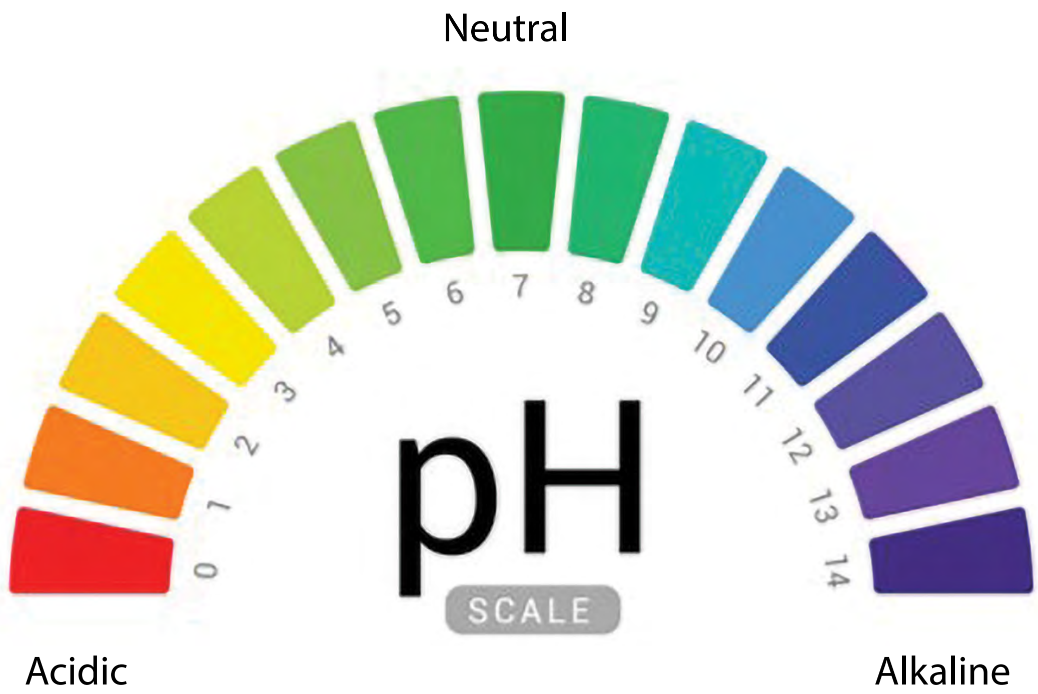
Postharvest

Postharvest chemical interactions

Understanding basic facts about the chemistry of postharvest sanitisers and chemicals is critical to successfully using them without compromising efficacies.

Some citrus packers use two types of sanitisers in the postharvest washing line in a sequential manner. For example, the fruit are first washed with water containing chlorine (effective at neutral/slightly acidic; pH ≤ 7.0), followed by washing with water containing PAA (effective at low pH; ≤3.5).

The higher pH of chlorine in residual wash water on the fruit surface could potentially reduce the efficacy of PAA by increasing the pH of the PAA solution as time progresses during processing.



Consider the pH factor when adopting postharvest chemical treatments such as sanitisers, fungicides and other compounds such as sodium bicarbonates.

Postharvest

Some citrus packers treat fruit with sodium bicarbonate solution (1–2%; pH 8.5 to 9.0) before fruit washing for postharvest disease control and argue its role in wound repair. If sodium bicarbonate is to be applied before fruit washing, a rinsing step should be added between bicarbonate and sanitised wash water treatments, especially if PAA is being used.

Similarly, the effect of residual wash water pH on the subsequent fungicide treatment should be considered. Using air blast/knives to remove excess moisture from the fruit surface during such conflicting pH scenarios could also be adopted.

Postharvest

Postharvest fungicides

Fungicides are commonly used for pre-washing, drenching, post-washing and waxing.

Approximately 25% of citrus packers use high-volume drenching systems for fungicide applications, ~60% use fungicide spray application, and ~15% employ a combination of both methods. Two-thirds of packers also use a fungicide in wax.

Cold fungicide application is common, but one-third of packers use a hot fungicide treatment.

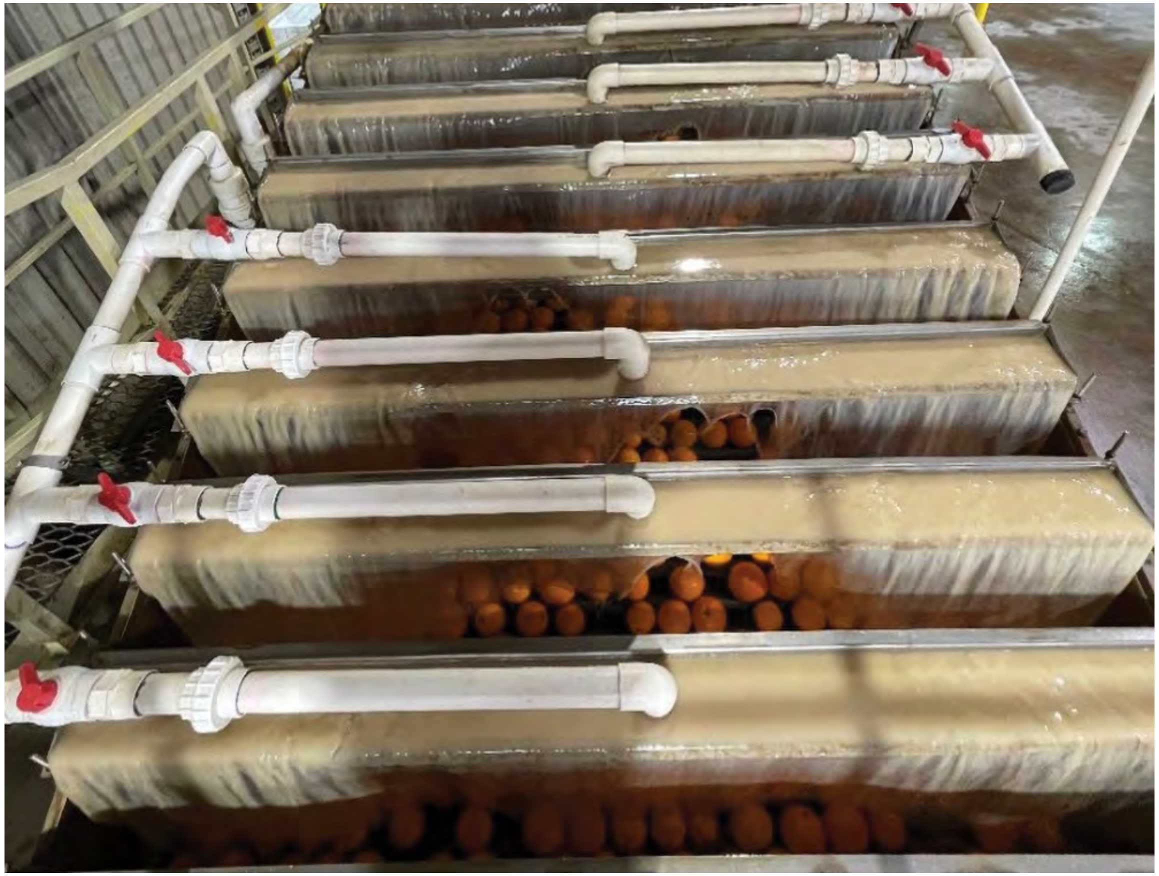
Sanitisation of high-volume drench systems could be a challenge. The frequency of fungicide change is critical.

Postharvest

Imazalil was the most commonly used fungicide, followed by thiabendazole, guazatine, fludioxonil and others.

Almost half of the citrus packers use 2 postharvest fungicides, ~19% of packers use 3 fungicides, and ~10% of packers use 4 fungicide options.

Using a sanitiser to sanitise fungicide solutions is uncommon. This could largely be attributed to the uncertainty about the compatibility of these products.



Fungicide solutions are meant for killing/inactivating moulds and generally do not have bactericidal effects.

Postharvest

From a food safety perspective, recirculating fungicide solutions is a cross-contamination opportunity for bacterial pathogens, which can survive in fungicide tanks. Fungicide solutions have to be effectively sanitised using sanitisers.

Sanitisers for recirculating fungicide systems need to be:

- compatible with fungicides
- not phytotoxic to the fruit
- odour-free
- non-irritant to workers
- fast-acting to kill human pathogens within a short time of ideally less than 30 s (although a 4–5 minute dwell time might be acceptable)
- should cause a >5-log-reduction in colony-forming units (cfu)/mL (Adaskaveg et al. 2021).

Listeria monocytogenes and *Salmonella* could survive in most fungicide solutions currently registered for postharvest applications in the citrus industry.

Postharvest

Fungicides and sanitisers compatibility

Unfortunately, some fungicides are incompatible with sanitisers. This incompatibility causes the active ingredient to break down, and the efficacy of the fungicide is lost. The manufacturers' recommendations must be followed when mixing products.

Imazalil, thiabendazole, fludioxonil, azoxystrobin, and pyrimethanil are compatible with PAA. Thiabendazole, fludioxonil, and azoxystrobin are compatible with sodium hypochlorite, while imazalil and pyrimethanil are incompatible with sodium hypochlorite (Adaskaveg et al. 2021).

Frequently clean and sanitise fungicide tanks to remove bacterial contamination. The compatibility of sanitisers and fungicides should be confirmed before mixing them in fungicide tanks.

Postharvest

Postharvest waxing

Carnauba is the most popular waxing material, followed by shellac and composite waxes. Carnauba is mainly used on mandarins, while shellac and composite waxes are common in oranges and lemons. The low-volume applicators are used for waxing the fruit, followed by the drying step.

Most citrus packers use wax containing imazalil fungicide, which is intended to provide residual protection against fungal pathogens in the supply chain. Wax on the fruit surface creates a moisture-rich microlayer between the fruit surface and the waxy top layer. The moisture-rich layer is conducive to foodborne bacterial pathogens surviving on the fruit surface.

Bacterial pathogens are capable of surviving in wax solutions (Sheng et al. 2023).

Postharvest

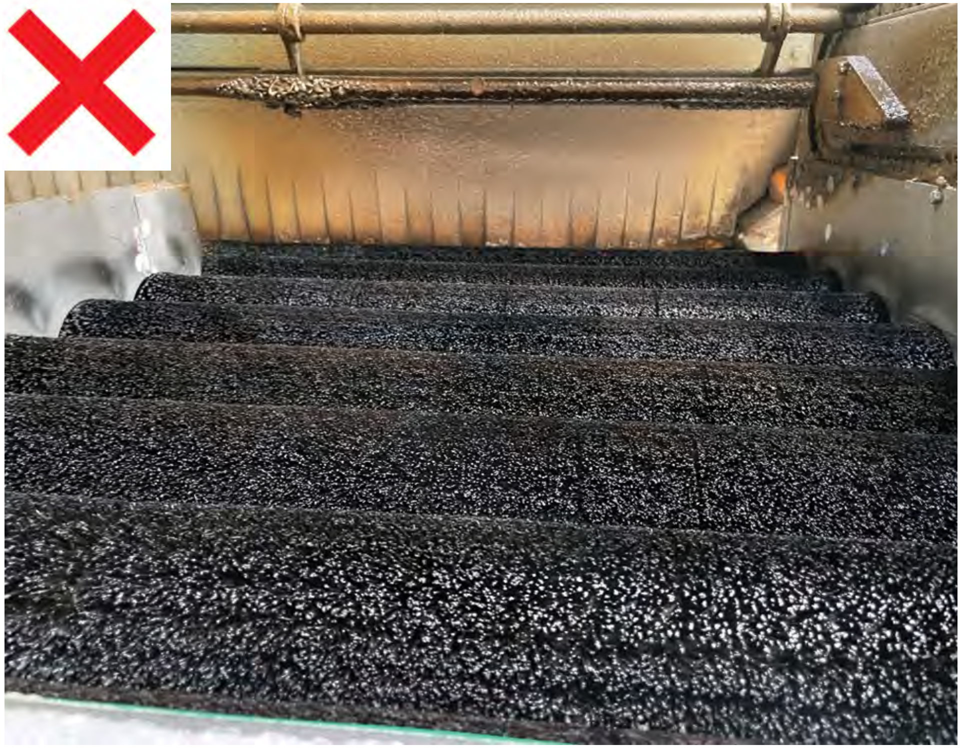
Waxes should be applied according to the rates recommended for various types of fruit.

Some citrus packers either use higher rates of wax application or do not properly clean and sanitise the post-waxing equipment, leading to excessive deposits of waxes on the conveyor belts and rollers.

Bacterial pathogens have been detected in waxy deposits, suggesting it could be another hotspot for cross-contamination of washed, sanitised, and waxed fruit ready for shipping.

Waxes should be applied according to the rates recommended for various types of fruit.

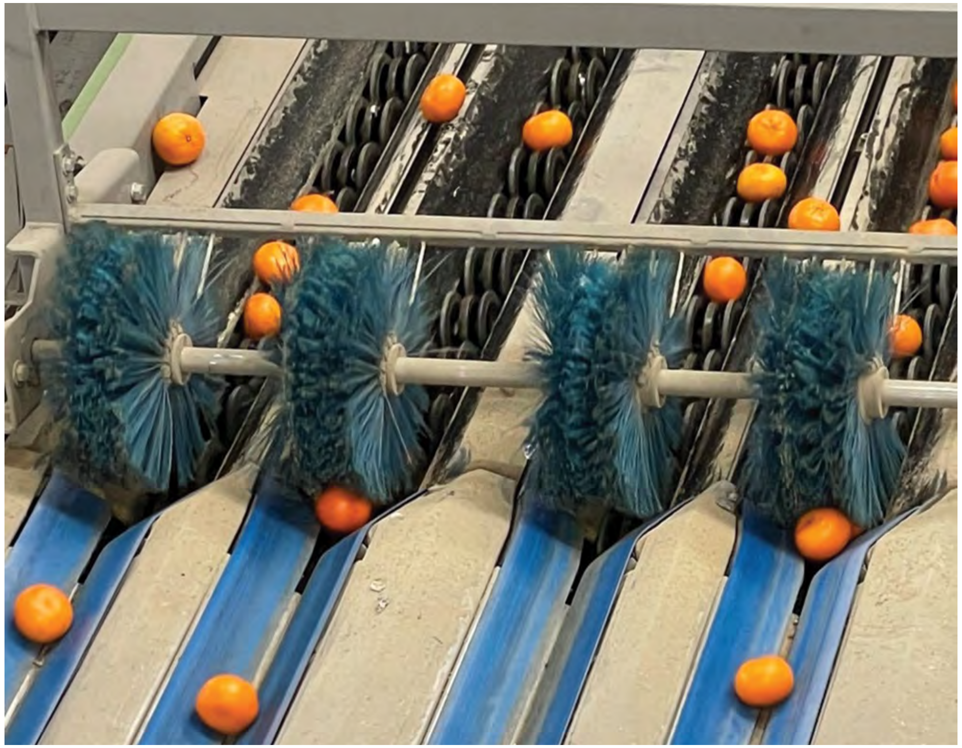
Postharvest



Post-waxing brush rollers should be regularly cleaned with food-grade detergents to avoid the deposition of excessive waxes, as pathogens can survive in these waxy deposits.

Postharvest

Some citrus packers use overhead brushes to give a finishing touch to the waxed fruit. These finishing brushes could get contaminated with *Listeria monocytogenes*, leading to cross-contamination of fruit.



Using overhead brushes to give a finishing touch to waxed fruit should be avoided. If they are used, clean the brushes with food-grade detergents and sanitise regularly to avoid the risk of cross-contamination.

Postharvest

Cool rooms

Processed fruit is held in cool rooms, which are generally maintained at or below 5 °C. The cooler conditions are not conducive for bacterial growth, but *Listeria monocytogenes* can survive and grow in cooler conditions.

Listeria monocytogenes has been regularly detected in samples collected from cool room floors and walls. Moving workers and forklifts can spread the pathogens from fruit receiving and processing areas to cool rooms and vice versa.

Listeria monocytogenes can grow and multiply in cool conditions (<5 °C).

Postharvest

Packing shed hygiene

Develop and implement postharvest environmental monitoring and management programs (EMPs).

Improve packing shed hygiene through proper cleaning and sanitisation tools and processes. Environmental monitoring and management programs (EMPs) benefits outweigh their costs.

Postharvest

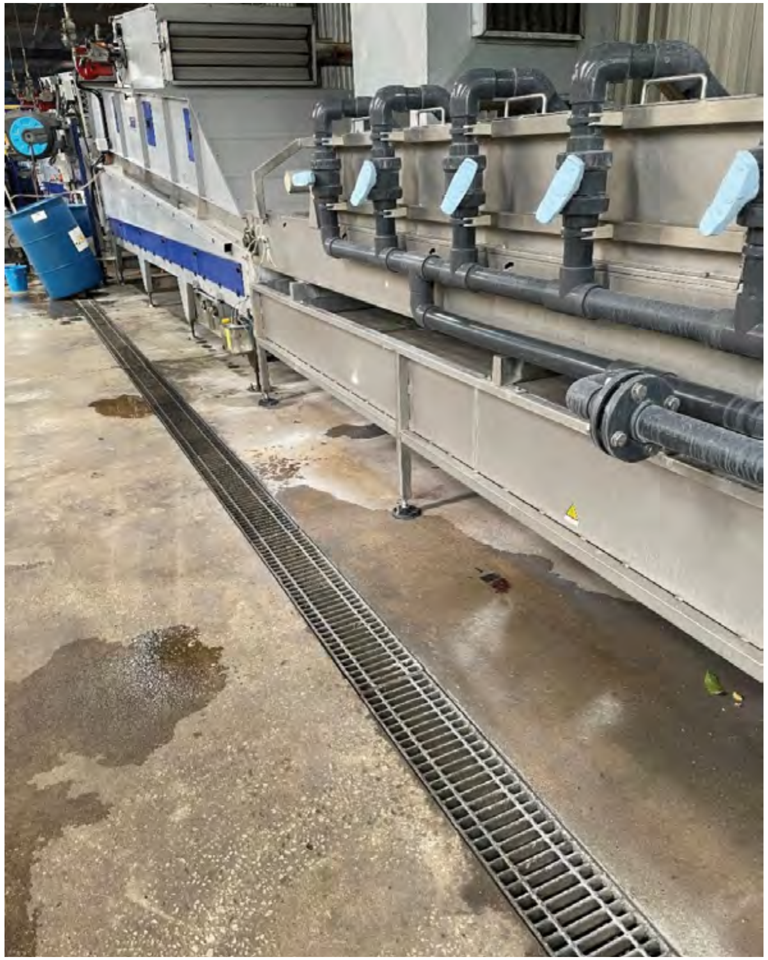
Packing shed equipment design and material should be easy to clean and sanitise.

Crevices and cracks, netting, and porous material attract and provide harbourage sites to environmental pathogens such as *Listeria monocytogenes*.

Postharvest

Drainage is an essential component of packing shed design. Older packing shed facilities do not have proper provisions for drainage. This limits the ability to clean and sanitise packing shed equipment and floors, allowing rapid run-off and wastewater disposal. The constant wet conditions in packing sheds provide an ideal environment for pathogen growth and survival.

Effective cleaning and sanitisation of drains is equally important to prevent pathogens from spreading from drains to other areas.



Proper drainage is critical to packing shed hygiene.

Packhouse environmental management program (PEMP)

1 Packhouse layout and design

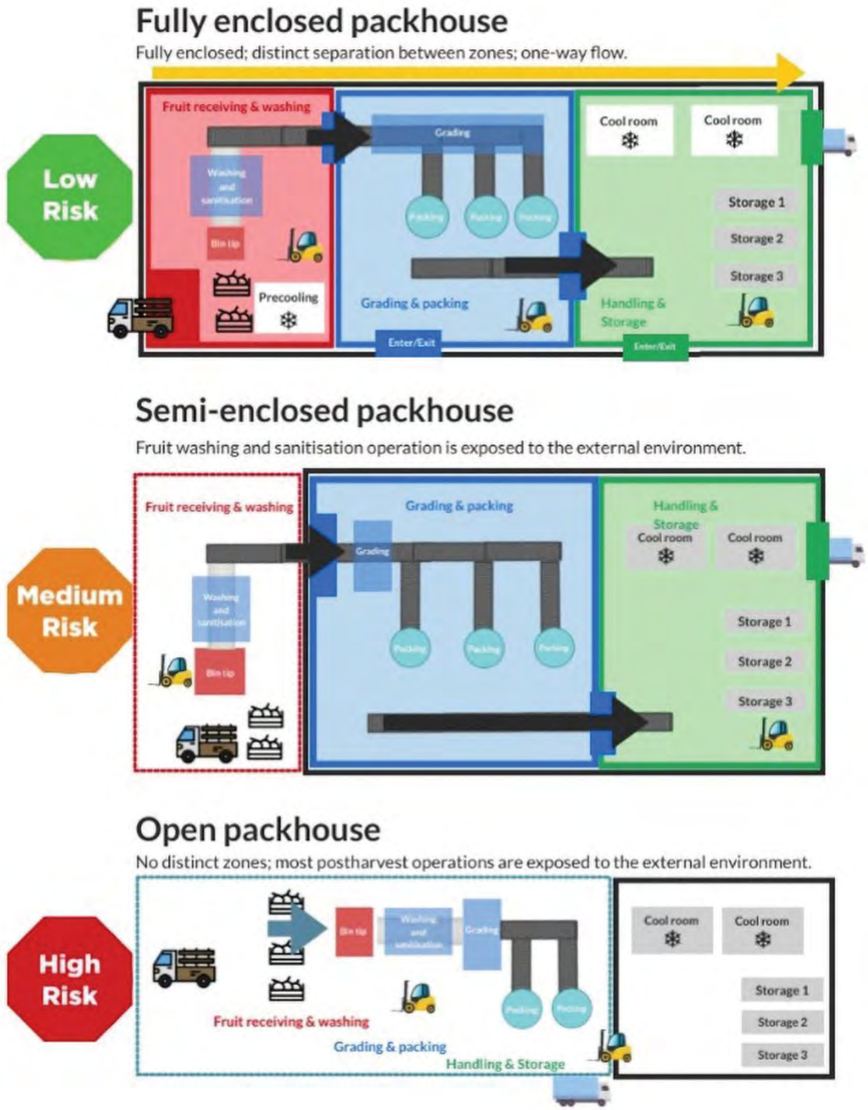
2 Postharvest processing flow

3 Equipment design

4 Cleaning and sanitisation

5 Environmental monitoring

Packhouse layout, design and processing flow



Packhouse identification zones

Zone 1: Fruit contact surfaces

- Conveyor belts
- Brushes - flatbed and overhead
- Hollow conveyor rollers
- Grading and sorting cups
- Packing tables
- Curtains in drying tunnels
- Harvest bins

Zone 2: Near-fruit contact surfaces

- Conveyor belts undersides
- Hollow rollers
- Weld seams
- Electrical cords
- Equipment stand/legs
- Metal cracks
- Bolt threads

Zone 3: Non-fruit contact surfaces

- Cracks in flooring
- Improper drains
- Rubber mats
- Plastic curtain strips
- Entrance.exit roll-up doors
- Drip pans under cooling units
- Cool room floors and walls
- Wash water/dump tanks
- Fruit waste areas
- Handwash stations

Zone 4: Outside packhouse area

- Locker rooms
- Cafeteria
- Hallways
- Loading dock
- Maintenance areas
- Offices

Seek and destroy the bugs

Why?

- To prevent transient pathogens from becoming entrenched, forming biofilms and spreading
- To verify the effectiveness of cleaning and sanitation measures
- To determine and undertake corrective action

How?

1 Target pathogens

- *Listeria species or L. monocytogenes*
- *Salmonella* species
- *Escherichia coli or E.coli*

2 How frequent?

- One size does not fit all
- Consider processing volumes and packhouse risk history
  - weekly testing for large operations (>20 tonnes/shift); bi-weekly for medium scale (3-20 tonnes/shift); and monthly for small packhouses (up to 3 tonnes/shift)
- Increase the frequency in the event of a positive detection and weather events (dust storms, flooding)

3 How many samples and from where?

- Determine on the basis of trends & risk history
- Minimum 5-7 swabs from each zone
- Minimum 5 processed fruit samples

4 When to sample?

- Immediately after packhouse sanitation and prior to processing
- During fruit processing, 2-4 hours from the start of the shift
- After packhouse cleaning, but prior to sanitation

5 How to sample ?

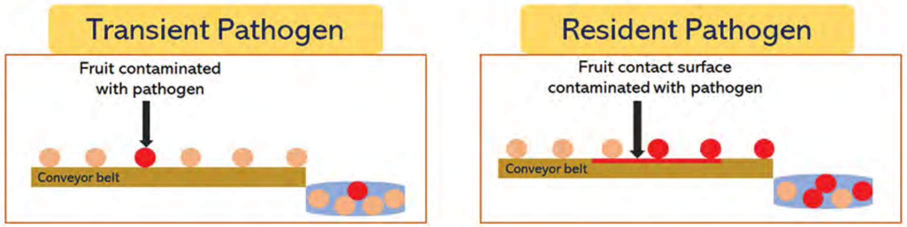
- Train QA staff in aseptic techniques
- Follow the sampling schedule as per food safety plan
- Use sponge swabs for sampling larger areas and Q-tip swabs for hard to reach niches
- Avoid compositing samples when targeting harbourage sites.
- Accurate labelling and documentation
- Pack samples with frozen gel-ice packs to maintain 0-4°C during transportation

6 Microbiological testing

- Contact an accredited laboratory service provider to select sampling swabs and testing
- Test reports to be documented for anlaysing trends and record-keeping
- Corrective actions to be undertaken in response to a positive detection

Understanding foodborne bacterial pathogen detection

Transient vs resident pathogens



Transient isolate is a one off isolate which is not detected after repeated swabbing (a minimum of 3 negative results in a row). This detection indicates that good manufacturing practices including cleaning and sanitisation are being implemented effectively. Pathogens such as Listeria may be introduced occasionally through incoming fruit and it is essential that best practices are used to keep occasional presence under control. Once introduced and not controlled a transient pathogen can take up residence.

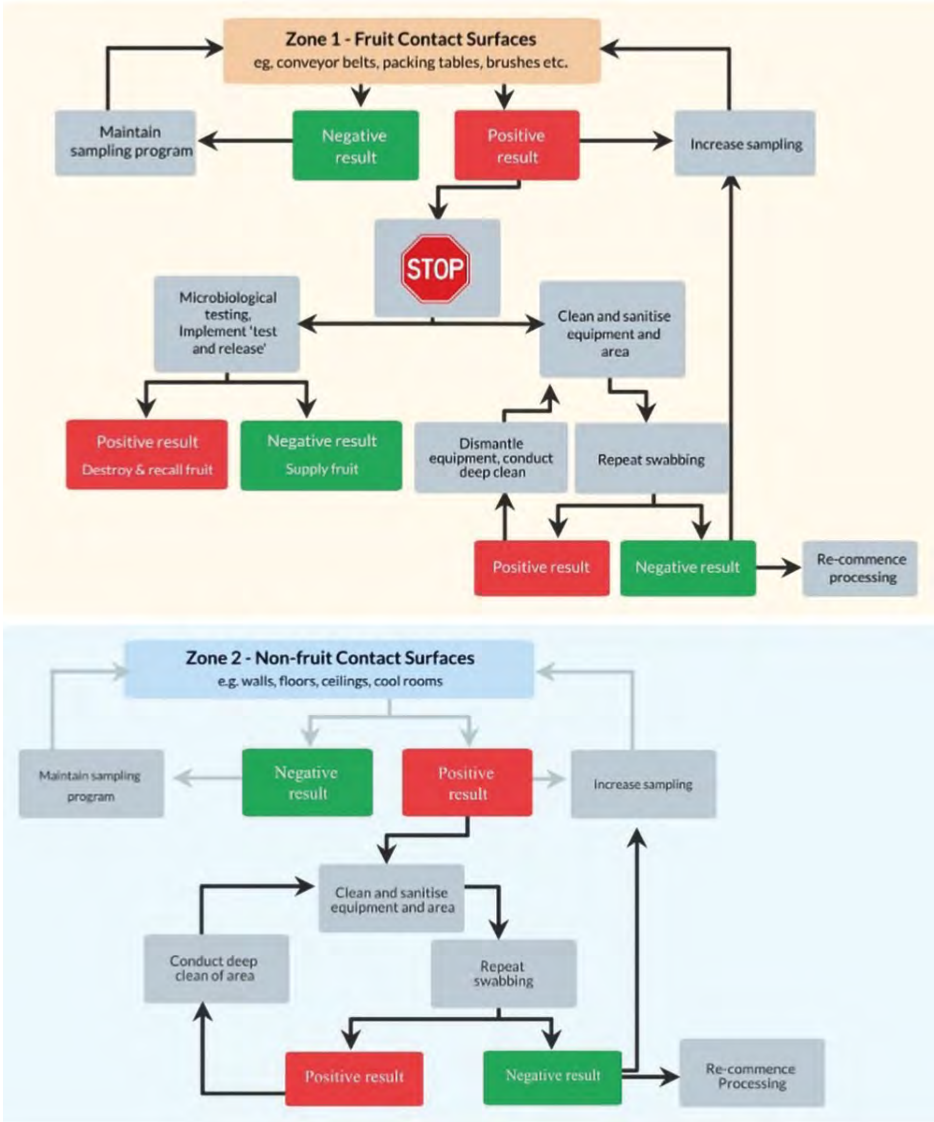
Resident isolate is an isolate that is repeatedly detected. This can indicate a failing implementing best practices in particular cleaning and sanitisation or an undiscovered niche where a pathogen has established a habourage site. There is a high chance that the site is continually re-contaminating the facility, increasing the potential for fruit to be contaminated. Processing should be stopped until repeated negative results can be produced. Aggressive corrective measures need to be implemented to seek out and eliminate resident isolates and assess the factors that allowed the site to be established.

First detection vs second detection

Occasional isolates can be brought in to the facility through incoming produce, however these must be prevented from continuing through the packhouse and taking up residence along the process. It can be expected that most detected isolates will be transient, from one location and not actually the source location. However, it is critical that this initial detection is not dismissed as a one off but is aggressively followed by testing to ensure it is not a resident isolate. If repeated detection occurs, an intensified response such as dismantling of equipment, deep cleaning and line shut downs are warranted.

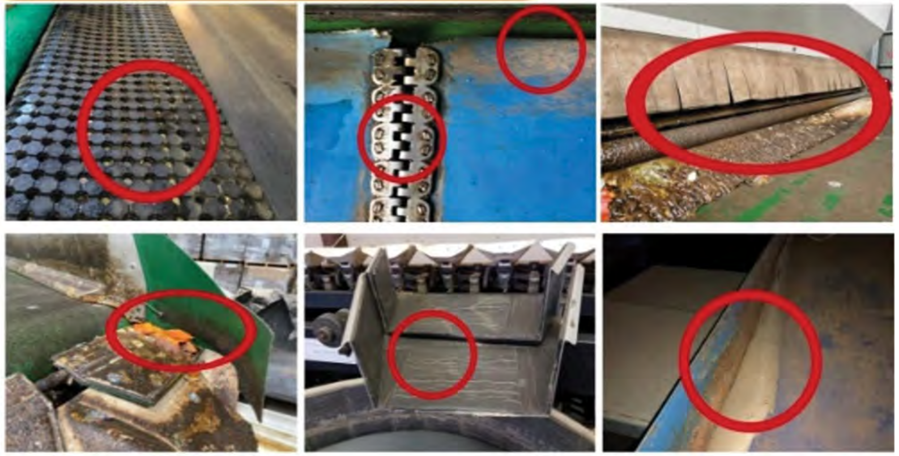
It is crucial that after first detection, the seek and destroy methodology is employed to identify niches and prevent habourage sites and future product contamination.

Responding to microbiological test results



Packhouse equipment design

Examples of bad equipment design



Best Practice

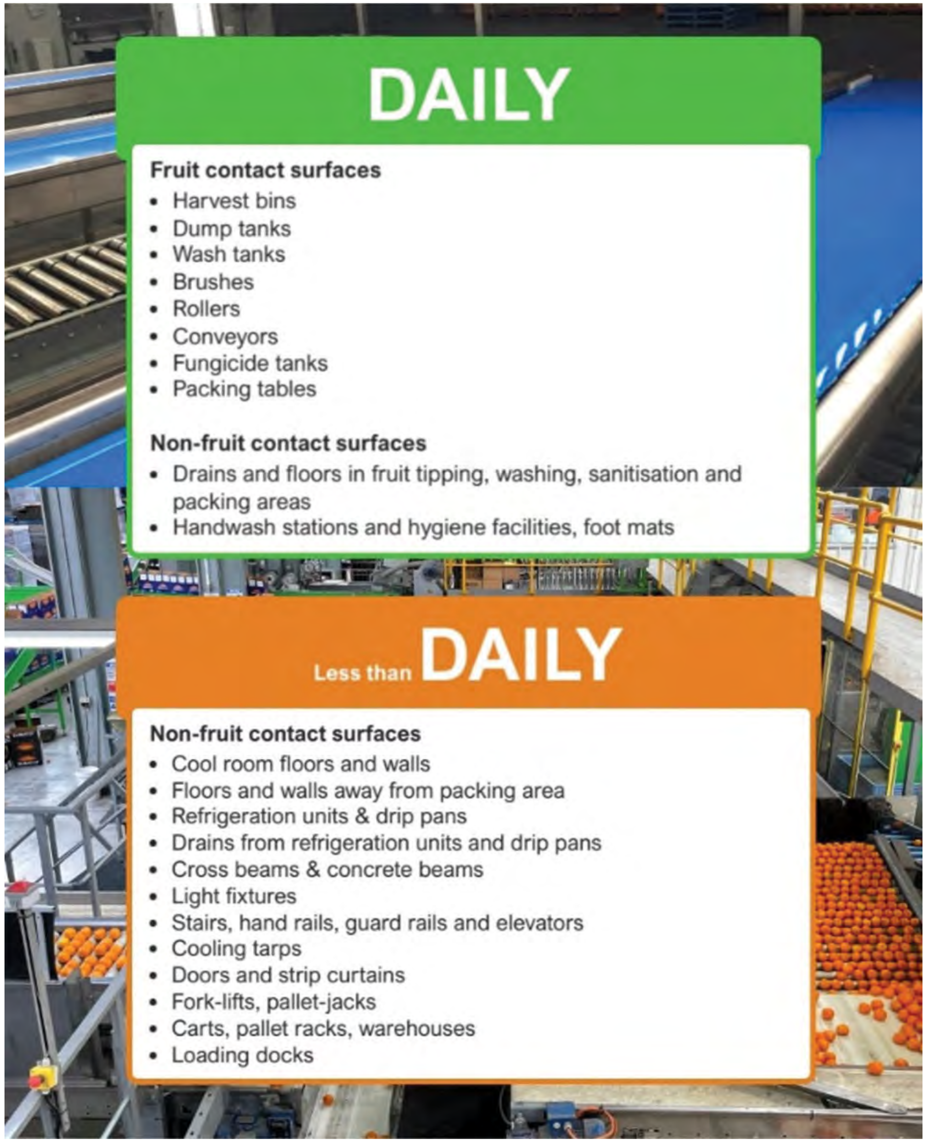
Equipment design should:

- be cleaning and sanitisation friendly
- be easy to disassemble and reassemble.
- be such as to have minimal areas for habouring bacterial growth
- consider sanitary materials and laminations

Equipment should:

- NOT have porous surfaces
- NOT have metal cracks
- NOT have sharp edges
- NOT have seams with metal or plastic lacing
- NOT have hollow rollers

Cleaning and sanitising schedule



DAILY

Fruit contact surfaces

- Harvest bins
- Dump tanks
- Wash tanks
- Brushes
- Rollers
- Conveyors
- Fungicide tanks
- Packing tables

Non-fruit contact surfaces

- Drains and floors in fruit tipping, washing, sanitisation and packing areas
- Handwash stations and hygiene facilities, foot mats

Less than DAILY

Non-fruit contact surfaces

- Cool room floors and walls
- Floors and walls away from packing area
- Refrigeration units & drip pans
- Drains from refrigeration units and drip pans
- Cross beams & concrete beams
- Light fixtures
- Stairs, hand rails, guard rails and elevators
- Cooling tarps
- Doors and strip curtains
- Fork-lifts, pallet-jacks
- Carts, pallet racks, warehouses
- Loading docks

Cleaning and sanitising

The terms 'cleaning' and 'sanitising' are often misunderstood and used interchangeably, resulting in the misinterpretation of recommendations; it is important to understand their differences.

Cleaning is the physical removal of soils such as dust, dirt, plant material, food residue or grim from the surface using products such as soap (or detergent) and water. While cleaning removes soils from a surface leaving them visually clean, it does not actually kill bacteria. However, by removing soils, pathogen numbers are lowered and subsequent sanitising is more effective. **Cleaning is the crucial first step in the process**. In order to kill and remove pathogens, sanitising will need to be performed after cleaning.

Sanitising lowers the number of bacteria and overall microbial load on surfaces or objects to a safe level. In the same way that cleaning does not kill pathogens, sanitising does not clean surfaces. It is critical that a surface is cleaned first, removing any soil that could influence the efficacy of a sanitiser. Pathogens hide under soils, essentially being protected from sanitisers.

Note: Not all sanitisers are food-grade and approved for use in food contact areas. Always check chemical manufacturers' guidelines and instructions for use.

1 Clean

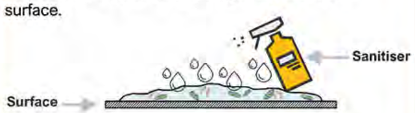
Pre-rinse target surface with water to loosen and remove soil and debris. Apply detergent and scrub the surface properly. Mechanical force, concentration, time and temperature are four factors influencing cleaning efficacy.

2 Rinse and inspect

Perform a post-rinse step to remove detergent and remaining soil and debris loosened by washing. Rinse equipment and other surfaces from top to bottom. Conduct a visual inspection to assess effectiveness of cleaning.

3 Sanitise

Use approved chemicals sanitisers at recommended concentrations and contact times for effective sanitisation. A proper cleaning step ensures interaction of sanitiser with potential pathogens present on surface.



4 Validate and verify

Validate your cleaning and sanitisation schedule as per the food safety plan. May use adenosine triphosphate (ATP) swab analysis to verify the surface has been effectively cleaned and sanitised.

Note: ATP is a cleaning verification system that counts the number of living cells on a sample you take from a surface. By testing the ATP levels on a surface, you can determine the effectiveness of your cleaning and sanitisation.

Cleaning and sanitising: things to consider

Dwell time - The 'wet dwell' time varies between products depending on their registration, so it is important to follow recommended times. If products are not given enough time to work, pathogens are left behind and processes efficacy is reduced.

Drying - ensuring surfaces after cleaning and sanitisation are dry to prevent the growth of pathogens e.g. avoiding pooling water.

Avoiding aerosols - avoid creating aerosols through high pressure washing and vigourous scrubbing that could lead to movement of soil and pathogens to clean and sanitised areas.

Effectiveness of cleaning and sanitisation process - validating and verifying your cleaning and sanitisation process with the use of ATP and pathogen microbiological testing.

Portable water - It is important that water is potable (microbiologically fit for human consumption) and is properly monitored regularly for any potential harmful chemicals or microorganisms.

Drainage - should be designed to be easily cleaned and maintained. Drainage should be installed to support effective wet cleaning of processing areas. Floor channels should be open, shallow and easy to clean and connected to drain outside the processing area. Floor drains are potential hot spots *Listeria monocytogenes*.

Surface finish - cleanability of product contact surface relates to roughness or surface finish of product. Rougher surfaces are more difficult to clean. Surfaces should be smooth, continous and free from cracks, crevices, scratches and pits that can retain soil and microorganisms.

Design principle - consider all features of equipment including joints, fasteners, internal angles, bearings, controls, doors and panels.

Ease of dismantling - equipment should be dismantled as far as it is possible or practical to make all surfaces that microorganism could attach accessible for cleaning and sanitisation.

Hazards from cleaning and sanitising

Actions that may result in microbiological contamination

- Cleaning from low-to-high risk areas (i.e. areas more likely to be contaminated to cleaner zones)
- Using contaminated equipment for cleaning such as brushes and clothes
- Using incorrect chemicals or at wrong dilutions
- Movement of dust during sweeping or dry cleaning
- Creating aerosols by pressure spraying, floor scrubbing.

Actions that may result in microbiological survivor

- Not adequately cleaning surfaces prior to sanitising
- Inadequate type, concentration or contact time of sanitiser used.

Actions that may result in microbiological growth

- Ineffective cleaning and disinfection including incorrect frequency
- Failure to remove food debris thoroughly/frequently

Actions that may result in chemical contamination

- Use of wrong chemicals
- Use of chemicals at wrong concentrations
- Failure to rinse properly
- Incorrect storage of chemicals including storage containers used and storage location.

Appointed trained personnel with the responsibility of cleaning and sanitising the packhouse environment.

Summary

Fruit production

Orchard location

Risks

- Proximity to livestock operations
- Wildlife incursions

Management

- Establish buffer zones
- Manage run-off
- Plant windbreaks
- Use fencing and wildlife exclusion

Soil management

Risks

- Raw animal manure/partially composted manure
- Soil amendment application method/timing
- Orchard floor management

Management

- No animal manure
- Apply compost after harvest
- Use the band application method for compost
- Use cover cropping with orchard grass/sod for IPDM

Water management

Risks

- Upstream water contamination
- Irrigation water quality
- Pesticide application

Management

- Regular microbial testing of water
- Use better quality water for chemical sprays, especially from one month before harvest

Tree canopy management

Risks

- Leaf litter, moisture and low light under trees, are ideal for *Listeria* growth

Management

- Improve light penetration in the tree canopy
- Use skirting to expose the under-tree area to light

Harvest

	Risks	Management
 Harvest bins and picking bags	• Microbial contamination of harvest bins • Cross-contamination	• Clean and sanitise harvest bins after each use • Place harvest bins on trailers, not on the ground • Regularly wash fruit picking bags
 Fruit injury	• Fruit injury; cracks and openings for pathogens (fungal and bacterial) to enter	• Gentle handling of fruit by pickers • Avoid over-filling harvest bins • Careful fruit dumping in the packing shed
 Temperature management	• Fruit exposed to the sun will have reduced shelf life and increased microbial load	• Cover the harvest bins with a tarpaulin • Pre-cool fruit immediately after harvest
 Workers' health and training	• Health and safety • Food safety training	• Train workers not to pick damaged fruit or fruit with bird droppings on it, and not to pick fruit from the ground

Postharvest

	Risks	Management
 Fruit handling	• Holding fruit at ambient conditions • Delayed drenching with fungicide/ sanitiser • Wet dumping flume/tank cross-contamination	• Maintain cool chain after harvest • Preharvest fungicide drenching soon after harvest • Prefer dry dumping or maintain appropriate concentration of sanitiser in water flume/ tank with regular changes
 Washing and sanitising	• Inadequate sanitisers • Recirculating wash water • Cross-contamination through surfaces and postharvest chemicals	• Optimum sanitiser concentration and contact time • Recirculation – monitor water quality • Sanitise fungicide solutions • Brush rollers should be under water containing a sanitiser
 Fungicide treatment	• Fungicide solutions – a cross-contamination risk	• Regularly clean and sanitise fungicide tanks using compatible sanitisers • Determine the frequency of fungicide change based on organic and microbial load
 Waxing and drying	• Waxing can trap moisture on fruit surface, supporting microbial survival • Pathogens can survive in wax and waxy depositis on conveyor belts and rollers and brushes	• Post-sanitisation coonveyors/rollers should be kept clean • Follow wax application rate guidelines • Use food-grade detergents to regularly clean and sanitise waxing and post-waxing equipment
 Cool rooms	• Listeria can survive on cool room walls and floors	• Clean and sanitise cool room surfaces with appropriate products • Drip pan and condensate from cool room should be drained properly

Best practice guidance on a page

References

Adaskaveg JE, Förster H, Chen D and Nguyen KA (2021) Integration of postharvest fungicides and fruit sanitation treatments to optimize decay control and address food safety concerns. *Postharvest Pathology: Next Generation Solutions to Reducing Losses and Enhancing Safety*, pp. 153–161.

Harris LJ (2019) Characterization and mitigation of bacteriological risks associated with packing fresh-market citrus. Final project report, Centre for Produce Safety, USA.

Hort Innovation (2023) Australian Horticulture Statistics Handbook 2021–22. Horticulture Innovation Australia Limited, https://www.horticulture.com.au/globalassets/hort-innovation/australian-horticulture-statistics-handbook/ahsh-2021-22-fruit-r3.pdf

Jung J, Friedrich LM, Danyluk MD and Schaffner DW (2017) Quantification of transfer of *Salmonella* from citrus fruits to peel, edible portion, and gloved hands during hand peeling. *Journal of Food Protection*, 80(6), 933–939, https://www.sciencedirect.com/science/article/pii/S0362028X22097484

Kanetis L, Forster H and Adaskaveg JE (2008) Optimizing efficacy of new postharvest fungicides and evaluation of sanitizing agents for managing citrus green mold, *Plant Diseases*, 92: 261–269, https://doi.org/10.1094/PDIS-92-2-0261

Martinez-Gonzales NE, Martínez-Chávez L, Martínez-Cárdenas C and Castillo A (2011) Comparison of different washing treatments for reducing pathogens on orange surfaces and for preventing the transfer of bacterial pathogens to fresh-squeezed orange juice. *Journal of food protection*, 74(10), 1684–1691, https://www.sciencedirect.com/science/article/pii/S0362028X22115425

Parish ME (1998) Coliforms, *Escherichia coli* and *Salmonella* serovars associated with a citrus-processing facility implicated in a salmonellosis outbreak. *Journal of Food Protection*, 61(3), 280–285.

Rajapakse PJ (2016) Contamination of food and drinks: product liability in Australia. Deakin Law Review, 21, 45–70.

Sheng L, Wang H, Harris LJ and Wang L (2023) Survival of *Listeria monocytogenes* and *Salmonella* in citrus storage waxes or on lemons held under common commercial storage conditions. *Food Microbiology*, 115, 104339, https://www.sciencedirect.com/science/article/pii/S0740002023001260

Singh SP (2023) Flooding adversely affects fresh produce safety. *Microbiology Australia*, 44(4), 185–189.

Strawn LK, Fortes ED, Bihn EA, Nightingale KK, Gröhn YT, Worobo RW, Wiedmann M and Bergholz PW (2013) Landscape and meteorological factors affecting prevalence of three foodborne pathogens in fruit and vegetable farms. *Applied and Environmental Microbiology*, 79(2), 588–600, https://journals.asm.org/doi/10.1128/aem.02491-12

Suslow T, Sbodio A and Pinzon-Avila J (2019) Resolving postharvest harborage sites of *Listeria* protects Zone 1 surfaces. Final project report, Centre for Produce Safety, USA.

Weller D, Wiedmann M and Strawn LK (2015) Irrigation is significantly associated with an increased prevalence of *Listeria monocytogenes* in produce production environments in New York State. *Journal of food protection*, 78(6), 1132–1141, https://doi.org/10.4315/0362-028X.JFP-14-584

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