

Safe Leafy Veg

Best practice guidance



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Cover photo

Commercial crop production of leafy vegetables. Inset: a close-up view of a petri dish with dark bacterial colonies growing on the left side of an orange agar medium.

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Safe Leafy Veg Best practice guidance

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Introduction

The Safe Leafy Veg program, conceptualised and led by NSW Department of Primary Industries and Regional Development (NSW DPIRD), is a food safety initiative to reduce microbial risks in leafy vegetable production and post-harvest processing in Australia. Leafy vegetables are a cornerstone of healthy diets, valued for their high nutritional content, versatility, and growing contribution to food security and public health. Unlike foods that are cooked before consumption, leafy vegetables do not undergo a 'kill step' that eliminates harmful micro-organisms, meaning any contamination introduced during growing, harvesting, processing, or distribution can persist through to the consumer. Leafy vegetables are often grown close to the soil, have complex leaf surfaces, and are usually consumed raw or minimally processed, making them particularly vulnerable to microbial contamination. These inherent risks mean that robust microbial food safety risk management is a critical responsibility shared by all participants in the leafy vegetable supply chain.

A central component of the Safe Leafy Veg program is comprehensive microbial risk mapping throughout the leafy vegetable supply chain. Since starting in 2023, NSW DPIRD researchers have worked closely with producers and processors in major production regions to examine on-farm and post-harvest practices in detail. This has involved visiting sites, observational assessments, and collecting microbiological samples from irrigation water, soil, organic fertilisers, produce, processing equipment, wash water, and the handling environment. Extensive microbiological testing has been conducted to detect the presence of primary pathogens and indicator organisms to identify where contamination is most likely to occur and how it might spread or persist within production systems.

The program makes use of modern analytical and diagnostic techniques to deepen understanding of contamination pathways. Advanced microbiological methods, including molecular analysis and whole-genome sequencing, are used to track pathogens and distinguish between sporadic contamination and persistent environmental sources. This allows contamination reservoirs to be identified, the effectiveness of existing control measures to be assessed, and a better understanding of how factors such as weather, water quality, wildlife intrusion, and human handling contribute to food safety risks.

Industry engagement has been a defining feature of the program. Producers and processors participate voluntarily and are assured that all data are treated confidentially and reported only in an anonymised and aggregated form. This approach has fostered trust and encouraged

open sharing of information about current practices, challenges, and constraints. In return, participating businesses receive tailored feedback that helps them gain deeper insight into their risk profiles and identify practical opportunities for improvement.

By working collaboratively, NSW DPIRD has made the program a supportive tool for industry improvement rather than a compliance exercise. Importantly, the outcomes of the Safe Leafy Veg program align closely with recent changes to Australia's food safety regulatory framework. The introduction of Primary Production and Processing Standard 4.2.8 for leafy vegetables under the Australia New Zealand Food Standards Code establishes mandatory requirements for food safety management, traceability, and hazard control. The program provides producers and processors with the scientific evidence, practical guidance, and confidence needed to meet these obligations and transition smoothly into the new regulatory environment.

The **Safe Leafy Veg program** represents a forward-looking, evidence- and data-driven approach to food safety for leafy vegetable production. By combining rigorous scientific research with strong industry collaboration, it is improving understanding of microbial risks and translating that knowledge into practical, achievable improvements on farms and in processing facilities. The program not only contributes to safer food for consumers, but also supports the long-term sustainability and reputation of the leafy vegetable industry. Through continued research, development, and engagement, the Safe Leafy Veg program is helping to embed a culture of proactive food safety management, ensuring that leafy vegetables remain a safe and trusted component of the Australian food supply.



Major food safety challenges for leafy vegetable producers

The Safe Leafy Veg program team identified several recurring food safety challenges for leafy vegetable producers. While many food safety risks can be managed through good agricultural and processing practices, producers operate in a complex environment where external factors can significantly influence contamination risks. The following challenges were consistently identified through industry consultation, risk assessments and microbial risk mapping activities.

- **Extreme weather and climate variability:** flooding, heavy rainfall, storms, heatwaves and drought can significantly increase food safety risks by affecting water quality, increasing animal movement, promoting run-off and creating opportunities for crop contamination. Climate variability is increasing both the frequency and severity of these events, creating ongoing challenges for producers. Many of these factors are largely beyond the control of individual businesses, and even well-designed mitigation measures might not always prevent contamination.
- **Adjacent land uses:** many leafy vegetable farms are located near livestock operations, grazing land, feedlots and wildlife habitats. These can be sources of foodborne pathogens that can be transported onto production sites through run-off, dust, aerosols, flooding, wildlife movement or traffic. Implementing effective mitigation measures remains a significant challenge for many producers.
- **Water quality and availability:** access to safe irrigation water is becoming increasingly difficult in some production regions. Water sources can be affected by seasonal variability, drought, flooding, wildlife activity and upstream land use. Producers face increasing costs associated with water testing, treatment, monitoring and infrastructure upgrades to ensure compliance with food safety requirements and maintain water quality suitable for leafy vegetable production.
- **Increasing compliance and verification costs:** food safety certification, environmental monitoring, microbiological testing, water quality testing and regulatory compliance obligations continue to increase. While these activities are important for protecting public health and maintaining market access, they can impose substantial financial and administrative burdens, particularly for small- and medium-sized businesses. The costs associated with laboratory testing and auditing or verification programs were often identified by producers as a major challenge.

- **Balancing sustainability and environmental outcomes with food safety:** producers are increasingly expected to deliver both food safety outcomes and environmentally sustainable production practices. Horticultural and livestock industries have always co-existed and played an important role in nutrient recycling and sustainable agricultural systems. While using animal manure and other organic amendments can provide valuable agronomic and environmental benefits, they also require careful management to minimise the risk of pathogen contamination. Achieving an appropriate balance between food safety and sustainability requires science-based risk assessments, practical mitigation measures and a whole-farm, and in some cases, an area-wide approach, that integrates food safety, environmental stewardship and operational viability.



Mind the W framework

The 'Mind the W' framework has been developed through the Safe Leafy Veg Program following a comprehensive national review of current industry practice, factors affecting food safety and microbial risk mapping data (Singh et al. 2025). The process involved extensive engagement with producers and processors to ensure the framework was both scientifically robust and practical. The result is a simple communication and management framework that enables stakeholders with varying levels of food safety knowledge to understand the main sources and pathways of microbial contamination. It also reinforces effective risk management throughout the leafy vegetable supply chain.

The Mind the W framework identifies 7 interconnected risk areas ([Figure 1](#)):

1. **Water** use pre-harvest.
2. **Waste** from animal operations.
3. **Wind** from animal operations.
4. **Wildlife** and animal incursions.
5. **Weather** extremes.
6. **Washing** and sanitising.
7. **Workers'** health and hygiene.

Together, these 'Ws' represent the most significant pathways for microbial contamination to be introduced, spread, or amplified. The framework emphasises that managing one risk in isolation is insufficient. A holistic strategy is required where controls in one area reinforce those in others. This layered approach reflects the reality of leafy vegetable production, where environmental, biological, and human factors intersect.

Mitigating food safety risks requires a comprehensive and practical approach that translates scientific understanding into on-farm and post-harvest action. The Mind the W framework is designed to simplify the communication of complex food safety concepts and improve the adoption of best practices by producers and processors. It recognises that contamination risks do not occur in isolation and that effective management depends on understanding how multiple factors interact throughout production and handling systems. By presenting these risks in a clear and memorable structure, the framework encourages a proactive and preventative food safety culture.

Water is one of the most significant and well-documented conduits for microbial contamination in leafy vegetable systems. Surface water sources such as rivers, creeks, and dams are commonly used for irrigation but are highly susceptible to contamination from animal faeces, wildlife activity, run-off after rainfall, and upstream contamination. When contaminated water is applied

through overhead irrigation, particularly close to harvest, pathogens can be deposited directly onto edible leaves. Effective water management, therefore, begins with a thorough assessment of water sources, supported by regular microbiological testing to understand seasonal variability and contamination risks. As water quality often deteriorates during summer and following heavy rainfall or flooding, monitoring programs must be responsive and risk-based. Where water quality does not meet acceptable microbial criteria, mitigation strategies such as filtration, UV treatment, chlorination, or changes in irrigation source might be required to minimise direct contact with edible plant surfaces.

Animal waste, particularly when used as an organic soil amendment, represents another significant risk if not managed correctly. Raw or inadequately composted manure can introduce pathogens such as *Escherichia coli* (*E.coli*) and *Salmonella* spp. into soil, where they might persist for extended periods. These pathogens can then contaminate crops directly through splashing, dust, or indirect transfer via equipment and workers. Effective mitigation relies on validated composting processes that achieve sufficient time and temperature conditions to reduce pathogen loads, combined with careful handling, storage, and application of all soil amendments. Detailed documentation of amendment sources, treatment methods, and application timing is essential for traceability and informed risk assessment.



Figure 1. The Mind the W framework is designed to simplify the communication of complex food safety concepts and improve the adoption of best practices by producers and processors.

Wildlife and domestic animals are an ongoing and often unpredictable source of contamination. Faecal deposition by animals in growing areas can directly contaminate crops or soil, while grazing in or near production fields can compromise the safety of future plantings. Risk management in this area focuses on prevention and early detection with physical exclusion measures, habitat management, and routine field inspections. Establishing harvest exclusion zones where contamination is identified, managing livestock movements, and training workers to recognise and report animal activity are all critical components of a proactive control strategy.

Wind and weather further complicate food safety management by helping contaminants move through the landscape. Wind can carry pathogen-laden dust and aerosols from nearby animal operations onto crops or into open packing facilities. Extreme weather such as flooding, heavy rainfall, drought, and dust storms can rapidly increase contamination risks. Floodwater can transport pathogens from multiple sources over large areas, rendering affected crops and irrigation water sources unsafe. Effective management requires planning, including emergency response protocols, post-event assessments, clear harvesting exclusions, and resilient infrastructure designed to reduce the effects of extreme conditions.

Post-harvest washing and sanitising are critical steps for managing microbial risks but can become points of failure if poorly controlled. Excessive organic matter, poorly maintained equipment or inadequate sanitiser levels can allow pathogens to spread rapidly through wash systems, contaminating large volumes of produce. Strict control of wash water quality, use of potable water, careful management of approved sanitisers, and regular cleaning to prevent biofilm formation are essential. These systems must be validated and verified to ensure they consistently reduce pathogen load, particularly during periods of increased risk, such as following extreme weather.

Finally, **workers' health and hygiene** underpin the effectiveness of all other control measures. Human handling presents multiple opportunities for contamination if appropriate practices are not followed. Ensuring workers are healthy, well-trained, and supported by adequate hygiene infrastructure is fundamental to maintaining food safety. Ongoing training, clear procedures, and a culture that encourages accountability and reporting help embed food safety into daily operations.

The 'Mind the W' framework shows that the microbial safety of leafy vegetables depends on an integrated, evidence-based system rather than any single control measure. Each 'W' represents a potential vulnerability, and failure in one area can undermine the entire food safety program.

Through the Safe Leafy Veg program, this framework provides a practical and accessible guide for managing complex risks throughout the production and post-harvest continuum. By embracing its principles, the leafy vegetable industry can protect public health, maintain consumer confidence, and ensure the continued availability of safe, nutritious leafy vegetables.





Best practice guidance

This document provides guidance on best practice recommendations based on scientific research, food safety data, industry practice and international resources from leading regulators and industry organisations. However, it is not an interpretation of the Food Standards Code and does not have legal effect. Food Standards Australia New Zealand (FSANZ) has published guidance to support the implementation of the new primary production and processing standards for horticultural produce. This resource also provides practical advice on meeting the requirements of Standard 4.2.8 (FSANZ 2024).

The Food Standards Code is legally enforced in Australia through state and territory legislation. Businesses seeking advice on how to comply with the standards should contact their local regulatory authority ([Appendix I](#)).

Primary Production and Processing Standard for Leafy Vegetables (Standard 4.2.8)

Scope

- Applies only to leafy vegetables that are eaten raw.
- Covers activities from growing through early processing and transport.

Leafy vegetables and herbs that are commonly consumed raw or with minimal processing and where the edible portion consists primarily of leaves, shoots or stems. Examples of leafy vegetables and herbs covered by the Standard are in [Table 1](#).

Table 1. Leafy vegetables and herbs covered by the Australia New Zealand Food Standards Code Standard 4.2.8.

Leafy vegetables	Herbs
Lettuce (all varieties, including iceberg, cos, butterhead, oakleaf and specialty lettuces), baby leaf salad mixes, spinach, rocket (arugula), radicchio, mizuna, silverbeet (Swiss chard), kale, endive, chicory, tatsoi, pak choy (bok choy), choy sum, cabbage, wombok (Chinese cabbage), mustard greens, watercress, micro-greens, and spring onions.	Coriander (cilantro), parsley, basil, mint, dill, oregano, sage, thyme, and other leafy herbs commonly consumed raw or minimally processed.

The Standard generally applies to leafy vegetables and herbs that are supplied fresh and intended to be consumed raw or with minimal further processing. Businesses should consult their relevant regulatory authority where uncertainty exists regarding whether a particular commodity falls within the scope.

Definitions

- **Leafy vegetables:** any leafy crop consumed raw without cooking or a kill-step (e.g. lettuce, spinach, cabbage, kale, herbs, Asian vegetables, spring onions, micro-greens).
- **Growing site:** any site where leafy vegetables are grown, including fields, greenhouses, tunnel houses and hydroponics. It includes both soil and soil-less cultivation of leafy vegetables under open, partially covered and fully covered facilities, including vertical farming.
- **Harvest:** all activities associated with harvesting leafy vegetables, including picking, cutting, on-site packing (including retail packs), and transport to the next step in the chain.
- **Premises and equipment:** all facilities, structures, land, vehicles, and tools used in growing, harvesting, handling, storing, or moving leafy vegetables (e.g. knives, harvest bins, irrigation pipes, conveyor belts, sheds, pack houses, pre-coolers, and cool rooms).
- **Primary horticulture producer:** a grower or harvester of leafy vegetables.
- **Primary horticulture processor:** a business that carries out basic steps after harvest, such as washing, trimming, sorting, sanitising, storing, combining batches, early packing, or transport between processing sites.

Application

This Standard applies to primary horticulture producers and processors in Australia. It does not apply to the retail sale of leafy vegetables. It also does not apply to further manufacturing of harvested leafy vegetables, such as cooking, freezing, drying, preserving, blending, juicing, or adding other foods. The Standard only applies to Australian businesses involved in growing and processing leafy vegetables. In New Zealand, different legislation applies.

General food safety management requirements

Producers and processors of leafy vegetables must control contamination risks at every stage of their operations. To demonstrate this, they are required to maintain a documented food safety system. Businesses must prepare a **food safety management statement (FSMS)** and operate in line with their plan. An FSMS template has been developed as an example and is included in [Appendix 2](#). This statement must:

- identify potential hazards (biological, chemical and physical)
- specify control measures for each hazard
- provide evidence that these measures are implemented and effective.

The statement must be approved or recognised by the relevant authority (typically a state or territory food or primary production regulator). Businesses must also supply details such as their name, address, growing site locations, activities undertaken, and update information as required.

Producers and processors are responsible for managing hazards relevant to their production and processing steps. Hazards for leafy vegetables include:

- **Microbial:** *Listeria monocytogenes*, *Salmonella* spp., Shiga toxin-producing *E. coli* (STEC).
- **Chemical:** pesticide residues, spilt fuels or oils, cleaning agents, and chemicals used for water treatment or sanitation.
- **Physical:** toxic weeds, soil contamination, or foreign objects such as metal fragments from damaged equipment.

Businesses certified under an accredited food safety scheme (e.g. one recognised by the Global Food Safety Initiative) might already meet these requirements, subject to verification or recognition by the relevant authority.

Traceability requirements

Both **primary horticulture producers and processors** must have a system that can identify the source of leafy vegetables received and the destination of leafy vegetables supplied.

Every business must be able to account for all leafy vegetables it has grown, received, or supplied. This means having a traceability system that tracks produce **one step back** (where it came from) and **one step forward** (where it went; [Figure 2](#)).

Traceability is essential for quickly identifying and removing products from the supply chain if a food safety risk is detected. It also supports investigations into the cause of an issue. Rapid, targeted action lowers the risk to consumers and reduces costs for affected businesses.

The more detailed the records on suppliers and customers, the more effective the response. For example, if vegetables come from multiple sources, being able to identify the specific supplier or growing site for each batch allows recalls to be limited to only the affected lots. This highlights the value of a robust traceability system.



Figure 2. Packaged leafy salad bag with a QR code for accessing produce information and clearly labelled use-by and batch identification details.

An effective traceability system should include:

- **Traceability process:** clear procedures for recording producers, suppliers, customers, and produce details.
- **Supplier details:** name, address, phone, email, plus a description of the products or inputs supplied.
- **Customer details:** name, address, phone, email, and a description of the products supplied.
- **Transaction records:** dates of delivery or sale.
- **Identification codes:** batch numbers, lot codes, or other produce markings.
- **Quantity records:** amounts of produce received or supplied.
- **System testing:** regular mock recalls using realistic scenarios to verify the effectiveness of traceability.
- **Supporting records:** any other production records relevant to the business.

Traceability of inputs is a critical part of food safety management for leafy vegetables. Businesses must be able to identify the source, use, and movement of primary inputs such as **irrigation water, spray water, and organic soil amendments**. For water, this means recording the source (e.g. river, creek, dam, or municipal supply), treatment methods (if any), and dates of application.

For organic soil amendments, records should include the supplier, treatment process, batch or lot numbers, delivery and application dates. Maintaining these records ensures that, if contamination occurs, businesses can quickly determine whether a particular water source or soil amendment batch was involved. Effective input traceability not only helps rapid response and corrective action but also limits the scope of recalls, protecting both public health and business continuity.

Inputs – seeds, seedlings, soil, fertiliser and water

Primary horticulture producers and processors must take all reasonable steps to ensure that inputs do not contaminate leafy vegetables or render them unsafe for consumption. Inputs of concern include seeds, seedlings, soil, soil-less substrate, soil amendments (such as manure, biosolids, compost, plant bio-waste), fertilisers, and water.

Seeds and seedlings

Seeds and seedlings can be carriers of human pathogens in leafy vegetable production (Figure 3). While the risk of internalised pathogens at harvest is generally low, contaminated seeds can introduce and encourage the persistence of pathogens, highlighting the importance of using pathogen-free seeds and implementing strict hygiene controls in both field and hydroponic systems.



Figure 3. Seeds and seedlings can carry microbial contamination risks, particularly in hydroponic production systems.

Human pathogens such as *Escherichia coli* O157:H7 and *Salmonella* spp. can survive on seeds for extended periods (up to 2 years) and proliferate on seedlings after germination. Both pathogens have been recovered from lettuce seeds and seedlings, with *Salmonella* spp. showing higher survival rates than *E. coli* O157:H7 (Van Der Linden et al. 2013; Liu et al. 2017).

E. coli and *Salmonella* spp. in seeds can grow and disseminate throughout sprout and seedling tissues during germination. The extent of contamination depends on the pathogen species and the type of vegetable seed, with higher populations observed in alfalfa sprouts and fenugreek than in lettuce and tomato (Liu et al. 2017).

When seeds are contaminated, pathogens can become established on seedlings of crops such as lettuce and spinach, sometimes internalising within plant tissues. However, the risk of internalised pathogens persisting until harvest is considered low, although early-stage contamination increases persistence in the rhizosphere (Jablasone et al. 2005).

Both field and hydroponic production systems are susceptible to seed- or seedling-borne pathogen introduction, emphasising the need for pathogen-free seeds and preventive controls in leafy vegetable production (Riggio et al. 2019; Uhlig et al. 2021).

Hydroponic production of leafy vegetables

Hydroponic production systems for leafy vegetables in Australia can be fully enclosed (Figure 4), partially enclosed (Figure 5), or open (Figure 6). A significant proportion of lettuce, Asian leafy vegetables, herbs, and micro-greens are produced using hydroponic systems.

Contamination with human pathogens in hydroponic systems poses a significant food safety concern. The closed, water-based environment can facilitate the introduction and spread of micro-organisms such as *Listeria monocytogenes*, *Salmonella* spp. and noroviruses.



Figure 4. Hydroponic production of leafy vegetables in a fully enclosed facility.



Figure 5. Hydroponic production of leafy vegetables in a semi-enclosed facility.



Figure 6. Hydroponic lettuce production in an open environment.

While hydroponic cultivation is often considered a lower risk alternative to soil-based production, evidence shows that pathogens can persist in nutrient solutions and be absorbed into plant tissues, especially if system hygiene is compromised or contaminated water sources are used (Ilic et al. 2022; Topalcengiz et al. 2024).

Once pathogens are introduced into the system via contaminated water, seedlings, substrate, or handling, these pathogens can persist in the nutrient solution and rapidly disperse to multiple plants through root contact. The continuous circulation of water, coupled with favourable conditions such as neutral pH, moderate temperature, and the presence of organic matter, can promote pathogen survival and biofilm formation on system surfaces, including pipes, pumps, and trays. Pathogens introduced into hydroponic systems have been detected in both the nutrient solution and edible plant tissues for extended periods, even after system cleaning and water replacement, highlighting the potential for cross-contamination between crop cycles. The risk of contamination varies by system design, water source, and management practices, with reclaimed water and inadequate disinfection increasing the likelihood of pathogen presence.

Data from the Safe Leafy Veg program indicated the root zones of hydroponically grown leafy vegetables are hotspots for pathogen detection, most likely because roots provide pathogens with opportunities for attachment and growth, which was also found by Ilic et al. (2022). Having pathogens in the root zone can contaminate edible leaves during harvest and post-harvest handling, including display at retail due to stacking.

Preventive measures such as routine microbiological testing, using treated water, and regular system sanitation are critical to minimise the risk of human pathogen contamination and ensure the safety of hydroponically grown produce.

Field production of leafy vegetables

Soil serves as a reservoir for human pathogens that can persist for long periods under favourable conditions. These pathogens can transfer to crops during growth, colonising roots and above-ground tissues (Figure 7). Harvest activities and irrigation can further spread contamination, while heavy rainfall and soil splash dramatically increase the risk of pathogen dispersal onto edible plant surfaces. Recognising these soil-to-plant transmission pathways is essential for managing food safety in leafy vegetable production.



Figure 7. Field production of leafy vegetables.

Soil texture significantly influences the survival and diversity of human pathogens such as *Listeria monocytogenes* and *Salmonella* spp., with finer textures (especially clay) providing a more stable environment for these microbes.

- **Clay-rich soil** has a high surface area and small pore spaces, which can stabilise and protect microbial pathogens, including human pathogens, by providing more attachment sites and shielding them from environmental stressors. This increases their persistence in the soil (Obayomi et al. 2019; Seaton et al. 2020; Xia et al. 2020).
- **Sandy soil** has larger pores and lower water retention, leading to less protection and shorter survival times for pathogens. Coarser textures generally have lower microbial abundance and diversity (Obayomi et al. 2019; Xia et al. 2020).

Soil texture, particularly high clay content, plays a crucial role in harbouring and supporting human pathogens such as *Listeria monocytogenes* and *Salmonella* spp. by providing a stable micro-environment that enhances their survival and diversity. This highlights the importance of considering soil physical properties when managing pathogen risks in agricultural and environmental settings.

The sticky nature of clay-rich heavy soil makes it difficult to remove from farm equipment, tools, and machinery, creating a pathway for pathogen transfer during field operations. When soil particles contaminated with pathogens come into contact with leafy vegetables, either during planting, growth, or harvest, they can cause localised contamination on leaves and stems. Moreover, this adherence increases the risk of cross-contamination within processing facilities, where residual soil on machinery can be a persistent source of pathogens. Understanding the interactions between soil type, equipment hygiene, and pathogen persistence is therefore critical for implementing effective mitigation strategies in leafy vegetable production.



15 cl
15 cl



Organic soil amendments

Organic amendments, including compost, manure, and plant residues, enhance soil health by increasing organic matter content, nutrient availability, and populations of beneficial microorganisms. These amendments improve soil structure, aggregation, water-holding capacity, and aeration, which collectively promote plant growth and enhance resilience against erosion and compaction. Long-term application of organic amendments enriches beneficial microbial communities, suppresses soilborne pathogens, and elevates concentrations of bioactive metabolites that contribute to plant development and soil aggregation. Moreover, increased microbial diversity in organically amended soil is associated with improved microbial functionality and higher crop productivity. The magnitude of these benefits is influenced by factors such as amendment type, soil pH, texture, climate, crop species, and especially the interaction between the organic matter and the soil.

Regulatory and market-based requirements

Australia – FSANZ Safe Horticulture Guidance

- Avoid using untreated manure or human waste.
- Purchase only certified, compliant, treated amendments (AS4454–2012).
- If producing amendments on the farm, ensure a validated, verified composting process is followed.
- Observe a minimum 90-day interval between the application of any amendment and harvest for crops grown close to the ground.
- Protect stored treated amendments from contamination.

United States

- The FDA Produce Safety Rule has not finalised a waiting period for raw manure. It requires practices that prevent direct or indirect contact between raw manure and produce.
- USDA National Organic Program (NOP) recommends a 90-day interval for crops where the edible portion is not in contact with soil; 120 days if the edible portion has direct soil contact.
- California Leafy Greens Marketing Agreement (LGMA) prohibits untreated manure in leafy vegetable systems. A 365-day exclusion interval applies to untreated or partially composted amendments, which can be reduced to 270 days if supported by soil testing and a documented risk assessment.

Compost

Compost containing plant residue and animal manure is generally regarded as safe from a microbial food safety perspective. The composting process can effectively inactivate or kill harmful foodborne pathogens when certain parameters such as temperature, aeration, moisture, and turning are properly maintained ([Figure 8](#)).



Figure 8. Windrow composting of spent mushroom substrate on a farm.

In Australia, compost that meets the requirements of [Australian Standard AS4454–2012 Compost, soil conditioner and mulch](#) is considered safe for use in fresh produce production. The standard specifies that:

- **Low-risk materials** (e.g. plant matter, vegetation) must undergo at least 3 turns, each with internal temperatures maintained at $\geq 55^{\circ}\text{C}$ for ≥ 3 consecutive days before the next turn.
- **High-risk materials** (e.g. animal manure, food waste) must undergo at least 5 turns, with internal temperatures maintained at $\geq 55^{\circ}\text{C}$ for a total of at least 15 days.

The composting process is expected to produce microbiologically safe produce. Compliance should be verified against Australian Standard AS4454–2012, Compost, soil conditioner and mulch. However, testing requirements for the final product ([Figure 9](#)) may vary depending on the requirements of state regulators ([Table 2](#)).

The AS4454–2012 is currently being revised. A recent technical review identified several shortcomings, most notably the lack of harmonisation throughout Australian jurisdictions, as well as inconsistencies between regulatory guidelines and market-driven requirements related to contamination (chemical, physical, and biological) and feedstock classification and risk (Wilkinson et al. 2024). This fragmentation creates challenges for both regulators and industry participants, particularly where compost and organic amendments are traded interstate.

Since its last update in 2012, there have been significant advancements in microbiological standards for organic products worldwide. At the same time, the organic recycling sector has transformed, with new streams such as food organics and garden organics (FOGO) becoming increasingly prominent. These changes, combined with growing awareness of emerging contaminants such as microplastics and ‘forever chemicals’ (PFAS and related compounds), underscore the need for the revised standard to overcome contemporary risks in a scientifically robust and internationally comparable way.



Figure 9. Sampling of compost for microbiological testing.

Table 2. Microbiological quality requirements as per AS4454–2012 versus state organic sector regulators.

Microbial quality indicator	AS4454–2012	NSW EPA (The Compost Order 2016)	Victorian EPA (Processed Organics 2021)
<i>Escherichia coli</i>	–	<100 MPN per g	<100 MPN per g
Faecal coliforms	<1,000 MPN/g dry weight	<1,000 MPN/g	<1,000 MPN/g dry weight
<i>Salmonella</i> spp.	Absent in 50 g dry weight	Absent in 25 g	Absent in 50 g dry weight

Most probable number (MPN) is a statistical estimate of the number of bacteria in a sample.

In addition to chemical contaminants, biological hazards remain a critical food safety concern. Current pathogen reduction criteria largely target bacterial indicators, but research and regulatory discussions are increasingly highlighting the importance of helminths (e.g. *Ascaris* spp.) and viruses (e.g. adenoviruses), which might persist through the composting process (NSW DPE 2023) and be transmitted when organic amendments are applied to fresh produce. These risks demonstrate the need for the updated AS4454–2012 to take a more holistic view of microbial safety.

A key recommendation of the technical review is the replacement of faecal coliforms with *Escherichia coli* (*E. coli*) as the preferred indicator organism for microbial safety verification (Wilkinson et al. 2024); this is already recommended by NSW and Victorian regulators. This aligns with international practice, as *E. coli* is considered a more reliable and specific indicator of faecal contamination. However, relying solely on indicator organisms might not sufficiently overcome food safety risks. Several international guidelines, such as those applied in fresh produce sectors, include requirements for specific pathogens. For example, the California Leafy Greens Marketing Agreement (LGMA) stipulates that compost containing animal-derived inputs must be:

- tested and shown to be free of *Salmonella* spp. and Shiga toxin-producing *E. coli* (STEC)
- verified to contain faecal coliforms <100 MPN/g of dry solids
- applied at least 45 days before harvest to reduce the risk of pathogen transfer to crops.

Beyond compost, the California LGMA extends food safety considerations to other organic amendments such as biofertilisers, biologicals, biostimulants, biopesticides, and compost teas. For materials not derived from animal sources, the guidelines specifically recommend testing for

the absence of *Listeria monocytogenes*, recognising its importance as an environmental pathogen with the potential to contaminate produce.

In the Australian context, the Safe Leafy Veg program provides additional guidance on safe compost use in fresh produce production systems. **Key recommendations include:**

- allowing the use of compost that complies with AS4454–2012 and relevant jurisdictional organic recycling regulations
- requiring producers to obtain and maintain documentation for each lot of compost, confirming that the supplier employed a scientifically valid composting process with appropriate process monitoring
- ensuring that any on-site composting operations are validated for their efficacy in producing a microbially safe organic amendment, with each batch verified through composite sampling and testing in accordance with AS4454–2012
- conducting additional microbiological testing of compost for priority pathogens such as STEC and *Listeria monocytogenes* as a verification step beyond compliance testing.

Together, these evolving requirements reflect a change in how organic amendments are managed, from a narrow focus on indicator organisms and minimum process requirements, towards a risk-based, multi-barrier approach that accounts for emerging contaminants, evolving scientific knowledge, and the critical importance of maintaining consumer confidence in fresh produce safety.

Untreated animal manure

Applying untreated animal manure in baby leafy production systems (e.g. spinach, rocket) is uncommon due to the high food safety risks associated with crops consumed raw. Limited use has been documented in some regions for leafy head crops (e.g. lettuce, cabbage) and spring onions, where practices vary depending on the farm, crop rotation schedules, and availability of organic amendments.

More commonly, producers incorporate poultry litter or cattle manure into the soil before planting (Figure 10). Some use aged manure and, in some cases, composted amendments as side dressings for leafy head crops (Figure 11) or top dressings for other crops.



Figure 10. Organic amendments should be incorporated into the soil before seeding or planting the crop.

Importantly, untreated manure is rarely applied immediately after it is generated. Instead, it is typically stored for days or weeks before application. During storage, stockpiles might heat internally, potentially reducing pathogens. However, because these stockpiles are not actively managed or aerated, heating is often uneven, and pathogen inactivation might be inconsistent.

Mixing compost together with raw manure is not recommended because it compromises microbiological safety. The survival of foodborne pathogens in manure-amended soil is highly variable, influenced by both environmental and management factors. Pathogens such as *Listeria monocytogenes*, *Salmonella* spp. and STEC can persist anywhere from a few days to several months, depending on soil temperature (higher temperatures generally accelerate die-off), moisture content (wet soil might prolong survival), soil type and texture, organic matter content, and environmental factors such as sunlight, UV exposure, and rainfall. This variability makes it difficult to establish a uniform safety buffer period and underscores the importance of science-based exclusion intervals and good agricultural practices.



Figure 11. Applying organic amendments as a top or side dressing over the crop canopy is high risk for produce contamination.

Aged manure is not equivalent to compost.

Organic amendments versus sustainability and profitability

Producers use untreated raw or aged manure in light-textured soil because of the agronomic benefits, such as ease of application, improved soil structure, and enhanced water and nutrient retention. In addition, compost, while relatively safer, could be twice as costly as untreated manure and increasingly difficult to source due to rising demand. These economic and logistical barriers create strong incentives for producers to use untreated manure.

However, the recommended exclusion periods for untreated manure (ranging from 90 to 365 days) pose significant challenges. They limit the efficient use of resources (e.g. land, water and capital), constrain farm profitability, and conflict with producers' ambitions to farm more

sustainably. Many producers see organic amendment use as a pathway to reducing reliance on synthetic fertilisers, lowering nutrient losses, and decreasing water use, outcomes that align with broader environmental and climate goals.

Despite these perceived benefits, producers remain acutely aware of the food safety risks. To overcome them, they adopt a variety of mitigation strategies, including microbiologically testing manure before applying it, planting cover crops after incorporating manure, and producing low-risk crops intended for cooking. While these measures demonstrate a proactive commitment to food safety, they lack robust scientific validation. Limited empirical evidence exists to confirm their effectiveness in reducing pathogen contamination, leaving producers uncertain about their true risk-reduction effect.

This tension between productivity, sustainability, and food safety underscores a pressing need for research-based, practical guidance. Without clear, evidence-driven recommendations, producers navigate complex trade-offs on their own. Robust scientific research and industry-supported guidance are essential to help them balance economic viability with food safety assurance, ensuring leafy vegetable production systems are both sustainable and trusted by consumers.

Interim recommendations

- Avoid applying untreated animal manure in leafy vegetable production systems.
- Assess the microbiological safety of aged manure before using it as a soil amendment and compare the results for compliance with the Australian Standard (AS4454–2012) for compost.
- Implement risk mitigation measures, such as growing cover crops after using untreated animal manure, or planting low-risk crops intended for cooking. A thorough risk assessment of the soil should be conducted before planting leafy vegetables.
- Incorporate organic amendments into the soil before seeding or transplanting, rather than applying them as top or side dressings to standing crops.
- Use compost only from certified sources. On-farm composting processes should be validated, and the final product should be tested to ensure it is safe for use.
- Participate in the Safe Leafy Veg program's soil organic amendment trials for the safe and effective use of organic amendments.



Water

Water quality in hydroponic leafy vegetable production

Water quality is a critical factor in hydroponic leafy vegetable production, as it directly affects both plant health and food safety. Hydroponic systems, while highly efficient for plant growth, can inadvertently create conditions that favour the survival and proliferation of foodborne pathogens. Several factors contribute to this risk.

1. Nutrient-rich medium

Hydroponic solutions are formulated to provide optimal nutrients for plants. These nutrients also serve as an excellent food source for bacteria such as *Listeria monocytogenes*, *Salmonella* spp. and STEC, and allowing them to survive and multiply in the solution.

2. Optimal temperature and pH

Hydroponic systems are often maintained at temperatures (usually 18–25 °C) and pH levels (around 5.5–6.5) that maximise plant growth. Unfortunately, these conditions are also within the growth range of many foodborne pathogens, facilitating their proliferation.

3. Water as a dissemination medium

Water in hydroponic systems continuously circulates through the system, providing pathogens with a medium to spread quickly throughout roots, leaves, and other plant surfaces. Contamination at one point can rapidly affect the entire crop.

4. Biofilm formation

Pathogens can attach to surfaces within hydroponic systems, such as pipes, tanks, and grow trays, forming biofilms. These biofilms protect bacteria from environmental stressors and sanitisers, allowing the bacteria to persist for long periods and repeatedly contaminate the nutrient solution.

5. Limited natural microbial competition

Unlike soil systems, hydroponic solutions often have limited microbial diversity. This reduced competition allows introduced pathogens to establish and multiply more easily than in a complex soil environment where beneficial microbes might suppress their growth.

Hydroponic solutions are essentially a nutrient-rich, moist, and moderately warm environment with minimal microbial competition, all of which can create near-ideal conditions for foodborne pathogens to grow, survive, and disseminate. Even low-level contamination can escalate rapidly, making rigorous water monitoring, sanitising, and pathogen control essential in hydroponic leafy vegetable production ([Figure 12](#)).



Figure 12. In hydroponic production systems, recirculating nutrient solutions can encourage microbial pathogen proliferation and biofilms.

Water quality in field production of leafy vegetables

Water quality is one of the most significant factors influencing the safety of leafy vegetable production in open-field systems, as water used for irrigation, chemical and nutrient sprays, frost and heat protection can directly introduce foodborne pathogens. Surface water sources such as rivers, ponds (Figure 13) and canals are frequently used in leafy vegetable production due to their availability and cost-effectiveness. However, they are also the most vulnerable to microbial contamination from animal faecal matter, livestock operations, sewage discharge, and run-off from surrounding agricultural land. When pathogens are in irrigation water, they can be spread onto leafy tissues such as lettuce, spinach, or kale, where they might persist until harvest and potentially survive post-harvest washing. This risk highlights the importance of continuous monitoring and management of irrigation water quality.

The irrigation method selected for leafy vegetable production plays a pivotal role in both water use efficiency and food safety risk. Overhead irrigation, widely used for spinach and other baby leaf crops because it cools the canopy and reduces heat stress, directly wets edible plant tissues, thereby increasing the likelihood of pathogen transfer when water is contaminated. In contrast, drip irrigation is considered the most food-safe method for leafy head crops (e.g. iceberg lettuce, cabbage), as it delivers water directly to the root zone and has minimal contact with edible plant surfaces, greatly reducing the chance of pathogen deposition. Regardless of the method, the timing of irrigation relative to harvest is critical; allowing sufficient time for environmental die-off of microbes between the last irrigation and harvest can reduce contamination risks.

Water sources

In leafy vegetable production systems, producers use a range of water sources, each with distinct hydrological characteristics, operational advantages, and food-safety implications.

Surface water sources such as rivers, canals and channels are commonly used. They provide large volumes but are subject to high seasonal variability and direct exposure to upstream land uses and run-off, which can rapidly alter microbial and chemical quality.

On-farm dams and ponds function as storage buffers that smooth supply over dry periods and allow some sediment to settle, yet remain open to wildlife, livestock, and storm-driven contamination.

Freshwater springs provide relatively protected, consistent flows but are prone to surface-derived contamination if the recharge area is exposed to livestock activity.

Rainwater harvesting from roofs and protected surfaces is often regarded as relatively clean for pre-harvest uses when collection systems are well maintained. However, its availability is directly constrained by rainfall and storage capacity.

Recycled or reclaimed water supplied from municipal or regional schemes can offer reliable, year-round volumes and reduce reliance on natural sources. However, its suitability for use on leafy greens depends on the level of treatment, monitoring regimes, and compliance with regulatory guidance.

Groundwater from borewells typically shows greater temporal stability and lower surface-derived microbial loads than open sources. However, aquifer quality varies geographically and can be compromised by salinity, geogenic contaminants, or anthropogenic inputs.



Figure 13. Surface water sources, such as farm ponds supplied by rivers and borewells, are commonly used in leafy vegetable production.

Industry practice (field production)

Surface water drawn from rivers and canals is first pumped into on-farm storage ponds, where it is sometimes blended with groundwater to achieve more consistent quality parameters for irrigation. This practice provides multiple benefits. Primarily, on-farm ponds act as a settling basin, allowing suspended sediment and particulate matter to drop out of the water before irrigation. This sedimentation process is not only important for preventing drip or sprinkler systems from clogging, but also for reducing microbial loads, since faecal indicator bacteria such as *Escherichia coli* often attach to organic particles and sediment. By removing a proportion of the suspended solids, the overall microbial population in the water can be significantly lowered before being applied to crops ([Figure 14](#)).



Figure 14. Surface water drawn from rivers is stored in farm ponds for sediment to settle and passed through a coarse filtration system.

Data from the Safe Leafy Veg program have shown this management step can have a measurable effect on microbial risk. Specifically, storing river water in ponds reduced *E. coli* populations by up to ten-fold, mostly due to sedimentation, natural die-off processes, and exposure to sunlight (UV radiation) in the storage system. Such reductions are critical given that leafy vegetables are typically consumed raw and therefore do not have a further kill step to eliminate pathogens before being consumed.

Further improvements in water quality can be achieved when pond-stored water is passed through filtration systems before field application. Using coarse filters to remove larger organic matter particles, combined with frequent backflushing to maintain filter performance, substantially reduces particulate loads and further limits the potential for microbial contamination reaching the edible portion of leafy crops. These interventions also reduce wear on irrigation infrastructure, improving system efficiency and longevity.

On some farms, water is pumped directly from rivers or creeks and applied to crops without intermediate storage or adequate filtration. This practice poses a higher food safety risk, as surface water sources are highly vulnerable to faecal contamination from livestock, wildlife, and upstream discharges. Also, microbial loads can fluctuate sharply after rainfall or flooding. Direct use of such water, especially via overhead irrigation where the harvestable portion of the plant is wet, increases the likelihood of transferring pathogenic micro-organisms onto leafy vegetables.

Storing river water in farm ponds, optionally blending it with groundwater, and applying filtration before irrigation, is a practical and evidence-based approach to reducing microbial risk in leafy vegetable production. Conversely, bypassing these steps and applying untreated surface water directly to crops remains a significant hazard, underscoring the importance of adopting best-practice water management strategies to protect both crop quality and consumer safety.

The Safe Leafy Veg data demonstrate that the microbiological quality of surface water, when measured by *Escherichia coli* populations, is highly dynamic and strongly influenced by seasonal and environmental conditions (Figure 15 and Figure 16). Trends from multiple water sources from different regions indicate that *E. coli* counts are generally higher during spring and summer (October to February) and after heavy rainfall and flooding, when contaminated run-off from

adjacent land use, including livestock operations, manure-amended soil, or urban effluent discharge, enters rivers, creeks, or on-farm storage dams. These can result in sudden spikes in *E. coli* populations, greatly increasing the risk of applying contaminated water directly to leafy vegetable crops. The higher *E. coli* population (>100 cfu/100 mL) has been linked to the presence of foodborne pathogens such as *Listeria monocytogenes*, *Salmonella* spp. and STEC in irrigation water.



Figure 15. Microbial quality of surface water varies with seasonal and environmental conditions.



Figure 16. Water sources can be affected by drought.

Currently, many leafy vegetable producers monitor irrigation water annually for quality assurance requirements. While this approach might be sufficient to demonstrate baseline compliance, annual testing alone is inadequate for effectively managing microbial risks. A single water quality measurement per year does not capture the variability caused by seasonal change, weather extremes, or unexpected contamination. Consequently, producers relying solely on annual monitoring might be unaware of periods when irrigation water poses a significant hazard to food safety.

To overcome this limitation, a comprehensive risk assessment framework should be adopted. This involves not only collecting and reviewing historical water quality data but also considering contextual factors such as source vulnerability, proximity to livestock or wildlife habitats, rainfall and flooding history, and the method of irrigation used. By analysing longitudinal datasets, producers can establish baseline microbial profiles for each water source, identify recurring high-risk periods and make informed decisions on water quality. In practice, this means water quality management should go beyond compliance-based testing and instead focus on an integrated systems approach that combines regular monitoring with preventive measures, such as sedimentation ponds, filtration, treatment technologies, and adaptive irrigation strategies. When implemented effectively, this approach provides a more robust assurance that irrigation water risks are being actively managed rather than merely documented for compliance. Ultimately, the evidence reinforces the principle that risk-based water management, combined with historical data and site-specific assessments, is essential for ensuring the microbiological safety of leafy vegetables. Moving from an annual compliance mindset to a dynamic, risk-informed strategy will help safeguard consumer health while supporting sustainable and resilient production systems.

Risk assessment

Assessing the risks associated with water for produce safety evaluates how factors such as water source, system design, environmental conditions, and adjacent land use can introduce biological or chemical hazards to crops. Effective control measures can then be implemented to prevent contamination. This system-based approach requires continuous assessment and mitigation to ensure water safety from source to application. A decision tree is provided to assist with water source risk assessment and to guide subsequent pre-harvest irrigation water quality management and decision-making (Figure 17).

1. The process begins by defining water uses for each field or block, including irrigation methods (e.g. overhead spray, drip, chemigation, frost protection), with heightened attention where water might contact the harvestable portion.
2. Next, the system is mapped, documenting sources (surface, groundwater, municipal, treated), storage, conveyance, treatment, sampling points, and potential cross-connections or backflow risks.
3. Hazards are then assessed for each water use, considering source vulnerabilities (upstream discharges, flooding history), adjacent land uses (livestock operations, composting, urban run-off, wildlife), system conditions (pipeline integrity, sanitation), weather (heavy rain, heat, flooding), and historical microbial data.
4. Based on this assessment, producers decide on and implement mitigation measures, which might include changing the water source or timing, adjusting treatments, improving filtration, pausing use, or delaying harvest to allow pathogen die-off, with reassessment following significant events.
5. Regular inspection is recommended at least annually and whenever major changes occur, and all activities, including assessments, water testing, corrective actions, and training, should be recorded using standardised templates to maintain an effective, auditable water safety program.

Pre-harvest irrigation water risk assessment for leafy vegetables

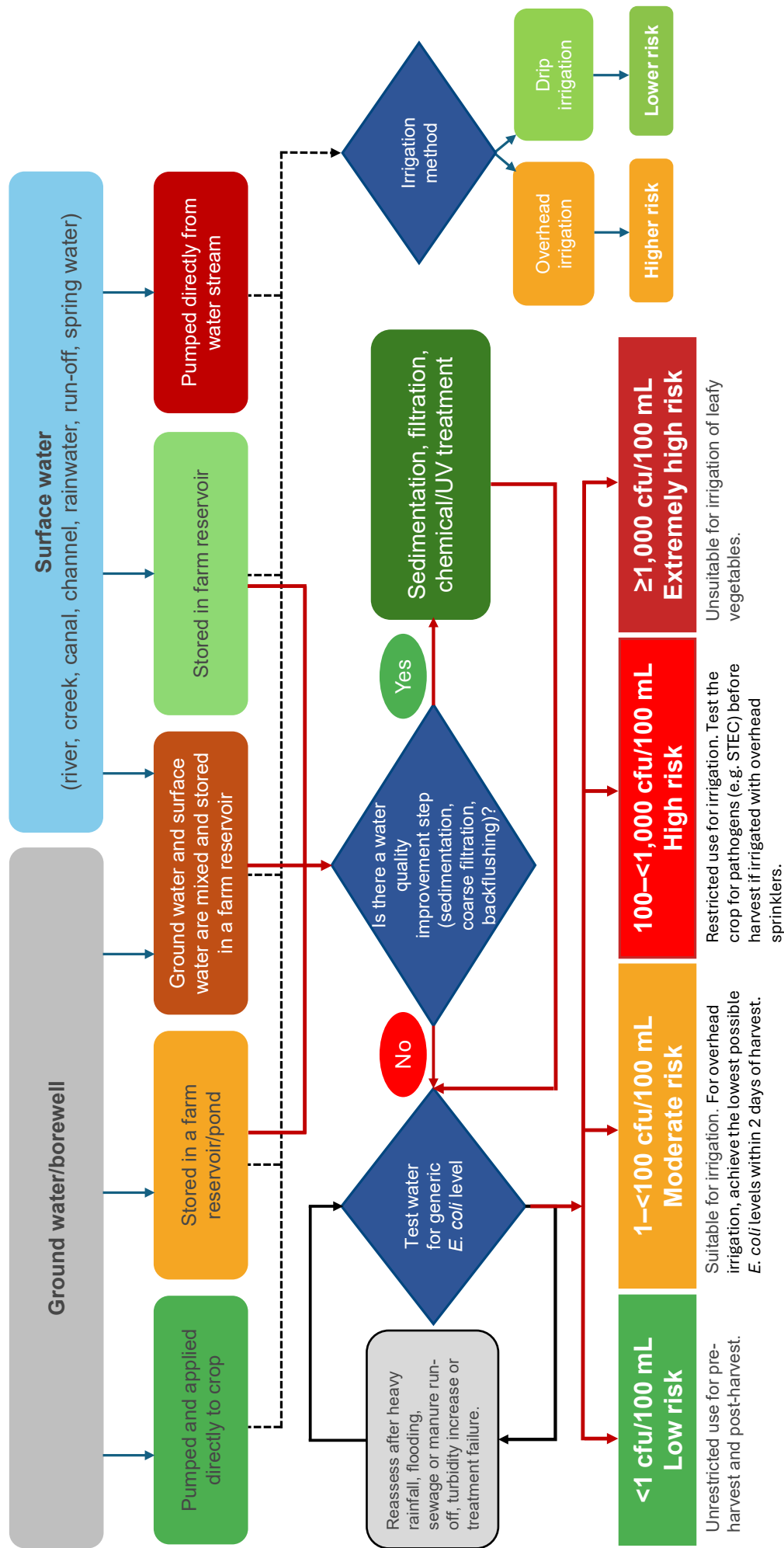


Figure 17. A decision-tree for assessing the microbiological quality and suitability of pre-harvest irrigation water used in leafy vegetable production.

Managing water quality

Monitoring water quality

Monitoring the microbiological quality of irrigation water is an essential part of leafy vegetable production, as it helps build a history of source safety and supports risk-based decision-making. As direct pathogen testing can be expensive and time-consuming, most programs rely on indicator organisms such as generic *E. coli* and total coliforms. The main goals of this testing are to establish baseline microbiological quality of water sources, identify temporal and spatial variations in microbial populations, support risk assessments for irrigation practices and inform management interventions such as filtration, disinfection, or changes in irrigation method or cropping pattern.

Water monitoring has several inherent limitations. Microbial populations in water are highly dynamic, influenced by factors such as rainfall (Figure 18), flooding, temperature fluctuations, and surrounding land use. Standard testing methods typically assume that micro-organisms are free-floating, which might underestimate populations attached to sediments or biofilms. Additionally, conducting monitoring at the frequency required to accurately capture these variations can be cost-prohibitive.



Figure 18. Water sampling from an irrigation channel after heavy rainfall, showing poor water quality.

Escherichia coli is not always a reliable indicator of the presence of target pathogens in agricultural water, as its correlation with actual pathogen occurrence is inconsistent and context dependent. While elevated *E. coli* levels are often associated with an increased likelihood of pathogens such as *Salmonella* spp. or STEC (Holvoet et al. 2014), other pathogens can still be present when *E. coli* concentrations are low, and vice versa. Water samples have a seasonal pattern, with both pathogens and indicator bacteria more frequently detected during warmer months (Shelton et al. 2011).

A study in Canada found pathogens in 80% of agricultural water samples with low *E. coli* concentrations (<100 cfu/100 mL), highlighting the risk of relying solely on *E. coli* (Edge et al. 2012). Similarly, research in Central Florida revealed that although all tested agricultural water ponds met the microbial water quality standards outlined in the US FDA Produce Safety Rule, pathogens were still detected, suggesting that meeting current regulatory standards does not guarantee pathogen absence (Topalcengiz et al. 2017).

Data from the Safe Leafy Veg study support these findings. Water samples meeting irrigation quality criteria (*E. coli* <100 cfu/100 mL) contained pathogens such as *Listeria monocytogenes*, *Salmonella* spp. and STEC. In fact, one in 4 samples with *E. coli* below 100 cfu/100 mL tested positive for a target pathogen, corroborating observations from previous studies in both Europe and North America.

Achieving statistically reliable results also requires frequent sampling, which can be prohibitively costly for smaller producers. To manage risk effectively, producers might need to complement testing with additional strategies, such as water treatment, improved filtration, or irrigation methods that minimise direct contact with edible plant tissues.

Physical and chemical treatment of water

Several physical and chemical treatment strategies have been investigated to reduce microbial contamination in agricultural water; however, their adoption for irrigation remains limited (Allende and Monaghan 2015). The large volumes of water required for crop irrigation present significant challenges in terms of both cost-effectiveness and operational feasibility. In the leafy vegetable sector, producers often manage multiple properties, sourcing water from diverse locations, which complicates the installation of permanent treatment infrastructure at every site.

Chemical sanitisers, particularly chlorine-based formulations, represent the most extensively studied interventions, although they have not been implemented in Australian leafy vegetable production. These treatments are effective in reducing foodborne pathogens, plant pathogens, and biofilm formation in irrigation systems (Raudales et al. 2014). Common formulations, including calcium hypochlorite and chlorine dioxide, are relatively inexpensive and readily available. Nevertheless, concerns remain regarding the potential formation of disinfection by-products, long-term environmental effects, and the substantial costs associated with treating high irrigation volumes.

Physical treatments provide environmentally sustainable and potentially cost-effective alternatives and have attracted increasing attention. Filtration systems (Figure 19), including for a range of pore sizes, are widely applied, with larger sand filters used to remove soil and organic debris. Further improvements in water quality can be achieved when pond-stored water is passed through filtration systems before field application.



Figure 19. An irrigation water treatment set-up on a farm.

The Safe Leafy Veg data showed that using coarse filters to remove larger particles of organic matter, combined with frequent backflushing to maintain filter performance, substantially reduced particulate loads and further limited the potential for microbial contamination to reach the edible portion of leafy crops. These interventions also reduce wear on irrigation infrastructure, thereby improving system efficiency and longevity. Multi-stage filtration systems, particularly when combined with complementary physical (e.g. UV-C irradiation) or chemical (e.g. ozone, chlorine) treatments, can further enhance pathogen reduction. UV-C irradiation has emerged as an effective disinfection strategy, particularly for low-turbidity water; however, pre-treatment via sand filtration and routine maintenance of UV lamps are essential to maintain consistent efficacy.

Integrating physical and chemical treatment approaches, tailored to specific water sources, irrigation volumes, and operational constraints, offers a flexible strategy for producers to improve microbial water quality while mitigating both environmental and operational risks.

Future research

The Safe Leafy Veg program is aimed at providing cost-effective and practical solutions for producers, focusing on minimising microbial risks associated with irrigation water. As part of this initiative, field-scale trials will be conducted on producers' properties to evaluate physical water treatment technologies and develop guidance on filtration systems and other interventions. These trials aim to ensure that microbial risks linked to pathogens are minimised to the greatest extent possible.

Certain protozoan parasites, such as *Cryptosporidium* spp. and *Cyclospora* spp., are not effectively inactivated by low doses of chemical sanitisers alone; therefore, filtration technologies combined with physical treatments represent a promising long-term solution for sustainable and cost-effective water management in leafy vegetable production.

Furthermore, there is an expectation to use drinking quality water for irrigation within 2 days of harvest of leafy vegetables, which is practically challenging for large-scale production. To overcome this, the program will engage stakeholders, regulators, and producers to define a new, science-based threshold for irrigation water quality that balances food safety with operational feasibility. This threshold would fall between drinking water standards (e.g. *E. coli* <1 cfu/100 mL) and current irrigation water standards (e.g. *E. coli* >100 cfu/100 mL), providing a realistic and protective benchmark for leafy vegetable production.

Pre-harvest water guidance

- Pre-harvest water quality is critical because irrigation water can come into direct contact with the edible portions of leafy vegetables, which are typically consumed raw and have a relatively short shelf life.
- Regularly conduct a comprehensive risk assessment of all water sources, considering both upstream and on-farm sources of microbial contamination. More attention should be given to surface water sources such as rivers, creeks, canals, channels, reservoirs, farm ponds, and spring-fed dams.
- Water pumped from groundwater into open storage reservoirs or farm dams should be managed as surface water. Similarly, spring-fed dams often have elevated baseline *E. coli* concentrations and require regular monitoring.
- **Adopt an area-wide catchment approach** to water quality management by identifying and monitoring upstream sources of faecal contamination, including livestock grazing, wildlife, intensive animal production, composting operations, wastewater treatment plants, and urban run-off.

- *Sedimentation is an effective process that reduces suspended solids, organic matter, and associated microbial contamination. Where practical, water pumped from rivers, creeks or canals should be stored and allowed to settle for 2–7 days before use.
- *Coarse filtration should be incorporated following sedimentation to remove residual suspended solids and organic matter. Frequent backflushing is essential to maintain treatment efficiency.
- Despite its limitations, *E. coli* remains the most practical and internationally accepted indicator of faecal contamination for routine microbiological assessment of irrigation water.
- **Pre-harvest irrigation water should contain <100 CFU *E. coli*/100 mL.**
- Where overhead irrigation is used, the lowest reasonably achievable *E. coli* levels should be maintained, particularly within 48 hours of harvest, to minimise direct contamination of edible leaves.
- Drip irrigation should be adopted (where possible) to minimise water contact with the edible portion, particularly for leafy head crops (e.g. iceberg lettuce, cabbage).
- The likelihood of detecting foodborne pathogens, particularly STEC, increases significantly when irrigation water contains >100 CFU *E. coli*/100 mL. If overhead irrigation with water (>100 CFU *E. coli*/100 mL) is used on leafy vegetables close to commercial maturity, the produce should be tested as described in the Microbiological Testing chapter on [page 89](#).
- Surface water quality is highly variable and can fluctuate seasonally with higher *E. coli* levels during warmer months and following extreme weather, particularly heavy rainfall and flooding. Reassess irrigation water quality following extreme weather or any event likely to affect catchment water quality, before resuming irrigation.
- Determine the frequency of irrigation water testing based on historical water quality trends, water source type, and a site-specific microbial risk assessment. For surface water sources, testing should be conducted at least annually for small-scale operations (<2 ha), once per crop production season for medium-scale operations (2–10 ha), and monthly for large-scale operations (>10 ha). Testing frequency should be increased following extreme weather, particularly heavy rainfall and flooding, or whenever there is a significant change in catchment conditions or water source characteristics.
- Routine monitoring should include *E. coli* as the primary indicator of faecal contamination. In addition, targeted pathogen testing for *Listeria monocytogenes*, *Salmonella* spp. and STEC is recommended where risk assessments identify elevated contamination risks, particularly for water sources influenced by livestock, intensive animal production, wildlife, wastewater discharges, or run-off following heavy rainfall.
- A risk-based monitoring program supported by historical data provides a practical and cost-effective approach to managing irrigation water quality while protecting food safety.

*This is an interim recommendation based on current evidence and requires further validation.





Growing sites

Assessing the risks of growing sites involves having a thorough understanding of the site's history, current surroundings, and any potential sources of contamination that could compromise produce safety. The assessment should identify and document the level of risk posed by each source of pathogen. Potential sources include, but are not limited to, manure storage areas, composting facilities and operations, animal operations (e.g. dairy, poultry), grazing land ([Figure 20](#)), domestic animals or hobby farms, natural habitats, sanitary facilities, water storage, conveyance systems and septic systems.



Figure 20. Having leafy vegetable farms near livestock production systems increases the risk of foodborne pathogens being transported onto production sites through run-off, dust, aerosols, flooding, wildlife movement or equipment traffic.

Producers are expected to assess topography, prevailing wind, water flow, drainage, and other contextual factors when determining appropriate separation distances in their risk assessments, with wider buffers where risks such as downslope positioning and wind-driven dust are present.

Buffer zones between animal operations and leafy vegetable production are a critical food safety measure for reducing the risk of contamination from pathogens associated with livestock and wildlife. These zones provide physical separation that limits the transfer of faecal matter, dust, aerosols, and run-off from animal operations into adjacent crop areas. The width and composition of buffer zones should be determined based on the type of animal operation, local

topography, prevailing wind patterns, and water flow to maximise their effectiveness. Well-maintained buffer zones can include grassed areas, vegetative strips, or unplanted land that help filter sediments, trap micro-organisms, and reduce the likelihood of contamination reaching crops. In addition, buffer zones provide space for monitoring and early detection of potential hazards, such as wildlife intrusion, allowing timely interventions before leafy vegetables are exposed. By incorporating appropriately designed buffer zones, producers add an essential layer of protection that complements exclusion fencing, windbreaks, and drainage systems, collectively safeguarding crop integrity and food safety.

The California LGMA provides guidance on recommended buffer distances between leafy vegetable production areas and potential sources of microbial contamination from animal operations.

- For moderate-sized feedlots with approximately 1,000 or more head of livestock, a buffer of around 366 meters (1,200 feet) is advised, representing an interim guideline adjusted from previous recommendations of 120 meters (400 feet) and serving as a baseline for risk assessment.
- For very large feedlots with more than 80,000 head, a buffer of about 1,600 meters (one mile) is recommended to provide additional protection against pathogen transfer.
- Active compost operations involving manure or other animal products should be located at least 120 meters (400 feet) from leafy vegetable fields, with actual distances adjusted according to site-specific risks and mitigation measures.
- Areas with low-density stocking rates and domestic animals should have a buffer of about 9 meters (30 feet), which can be increased depending on the assessed risk.
- Other animal operations, including hobby farms, follow similar guidance with a suggested distance of 9 meters, again subject to modification based on local conditions and risk evaluations.

Windbreaks ([Figure 21](#)), exclusion fencing, and other preventative barriers are essential tools for protecting leafy vegetable crops from microbial contamination. Wind can carry dust, soil particles, and aerosols containing harmful micro-organisms from nearby livestock operations, feedlots, or unmanaged areas directly onto crops. High-speed wind increases the potential for these aerosols to travel significant distances, bypassing standard hygiene controls and introducing pathogens onto plant surfaces. Strategically placed windbreaks, such as rows of trees or shrubs, reduce wind velocity and filter airborne particles.

Exclusion fencing ([Figure 22](#) and [Figure 23](#)) is a fundamental strategy for preventing animals and wildlife from entering leafy vegetable production areas, thereby reducing the risk of microbial contamination on crops. Well-designed fencing provides a physical barrier that prevents livestock, pets, feral animals, and wildlife from accessing growing fields, water storage areas, and irrigation infrastructure. Effective fencing requires careful planning, including selecting appropriate materials and heights, ensuring that gates and access points are secure, and considers local wildlife movement patterns. In addition to keeping animals out, exclusion fencing helps define controlled areas for monitoring, facilitates routine inspections, and enables buffer zones to be implemented. By integrating fencing with other preventative measures such as habitat management, rodent control, and windbreaks, producers can create a comprehensive defence system that significantly reduces the risk of contamination from both domestic and wild animals, safeguarding the safety and quality of leafy vegetables throughout the production cycle.



Figure 21. Perennial windbreaks consisting of tall hedges reduce the movement of airborne contaminants and contribute to the mitigation of food safety and biosecurity risks.



Figure 22. Fencing is critical for preventing animal intrusion.



Figure 23. Fencing and other physical barriers around water sources are critical to prevent access by livestock, wildlife, and other animals.

Proper drainage systems (Figure 24) reduce contamination risks associated with run-off and flooding from nearby operations. Floodwaters or surface run-off can carry pathogens, manure residue, and chemicals from adjacent fields, feedlots, or composting areas directly into leafy vegetable production zones. Well-designed drainage channels, retention ponds, and field grading help control the flow of water, preventing it from pooling in cropped areas and reducing the risk of pathogen transfer. By combining effective drainage with windbreaks and exclusion barriers, producers can establish multiple layers of protection that mitigate both airborne and waterborne contamination, ensuring safer leafy vegetables and enhancing food safety.

Best practice measures to ensure a growing site is safe and suitable include:

- Understanding the site's history, including previous crops, the presence of weeds, and chemicals applied, is crucial, as some weeds might be toxic or produce seeds that persist for years, and some chemicals can remain in the soil long term.
- Implementing buffer zones, exclusion fencing, windbreaks and appropriate drainage for securing the production sites.
- Conducting regular inspections of the site and surrounding areas to identify potential contamination sources, such as damaged fences allowing livestock intrusion or toxic weeds such as *Datura* spp.
- Routinely assessing hazards throughout the crop's life cycle, including at least once within the week before harvest.
- Pre-harvest pathogen testing is recommended for leafy vegetables grown near animal operations.



Figure 24. Drainage channels help mitigate microbial risks by reducing the movement of run-off, floodwater, and other contaminated flows into production fields.

Handling and storing organic amendments on growing sites

Organic amendments should be stored and managed to minimise the risk of contamination to growing sites, water sources, equipment, harvested produce, and the wider production environment. Improper storage can facilitate the spread of biological hazards through run-off, leaching, wind dispersal, animal activity, or cross-contamination ([Figure 25](#) to [Figure 28](#)).

Considerations include:

- Organic amendments should be stored in designated areas that are physically separated from growing sites, harvested produce, packing facilities, water sources, and irrigation infrastructure.
- Storage areas should be located on well-drained ground, with measures in place to prevent run-off or leachate from entering production areas, water bodies, or irrigation systems.
- Appropriate containment measures, such as covered storage areas, bunding, concrete pads, or barriers, should be used to minimise contamination risks ([Figure 29](#)).
- Stored materials should be protected from wind dispersal and access by livestock, wildlife, birds, and pests.
- Untreated, partially treated, and fully treated organic amendments should be clearly segregated to prevent cross-contamination.



Figure 25. Open storage of organic amendments can increase the risk of airborne and run-off-related microbial contamination.



Figure 26. Composting operations should be located away from water sources and screened to minimise windborne and run-off-related contamination risks.



Figure 27. Storing organic amendments next to the crop can increase the risk of airborne microbial contamination.



Figure 28. Improper storage of organic amendments in a wheelbarrow adjacent to a poly tunnel used for leafy vegetable production on a small farm.



Figure 29. Appropriate storage of organic amendments on a concrete floor and in a walled area that is isolated from field production areas.





Weather

Extreme weather is intensifying both in frequency and severity worldwide. This includes flooding, cyclones, drought, dust storms, bushfires, and prolonged heatwaves, all of which can have profound effects on horticultural systems. In particular, horticultural production and post-harvest operations are highly vulnerable, as extreme weather can disrupt planting schedules, damage crops, reduce yields, and compromise storage and transport. While the direct effects of such weather on crop losses are widely recognised, the broader implications for microbial food safety, especially for fresh horticultural produce, remain comparatively underexplored. Extreme weather is known to exacerbate microbiological contamination risks in fresh produce, considering both pre- and post-harvest stages.

Flooding

Flooding is the most frequent natural disaster affecting the leafy vegetable industry. Floodwater can carry biological, chemical, and physical hazards that compromise food safety during the production and processing of fresh produce. Run-off from livestock, industrial, residential, and sewage treatment areas can contaminate water sources, fields, and processing facilities. Short-term effects include transient increases in faecal indicators such as *Escherichia coli* and detection of pathogens such as *Listeria monocytogenes* and *Salmonella* spp. in produce, soil, water, and facilities, often leading to significant food losses and potential foodborne illness. Long-term effects are more severe, as microbial pathogens can persist in soil, water, and the processing environment.

Flooding can be broadly classified into 2 types:

1. **Rainfall-induced** accumulation in production fields, which promotes microbial contamination via overland flow and soil splash onto crops.
2. **Severe natural-disaster** flooding from rivers, lakes, or dams, which inundates fields and post-harvest facilities.

Floodwater might carry biological hazards (bacteria, viruses, parasites), chemical contaminants (residues, heavy metals, toxins), and physical hazards (wood, metal, glass) into the food production system (Figure 30). For example, a study in Spain reported that irrigation water, soil, and lettuce sampled one week after flooding had coliform and *E. coli* levels exceeding 5 and 3 log cfu/g or 100 mL, respectively (Castro-Ibáñez et al. 2015). Pathogens including *L. monocytogenes*, *Salmonella* spp. and STEC were detected in lettuce, soil, and irrigation water shortly after flooding, although bacterial populations declined significantly after 3 weeks.

Flooding risk management

- Undertake flood mitigation measures. Clearly identify and mark flood-affected zones to prevent cross-contamination with unaffected areas.
- Treat leafy vegetables exposed to floodwater as adulterated and unfit for consumption. Crops with limited exposure should undergo a thorough risk assessment, including microbial testing, before harvesting.
- Allow a waiting period of 30–60 days before replanting flood-affected fields, considering pathogen die-off rates, temperature, soil type, and crop characteristics. Consider replanting crops with edible parts above the soil or those intended for cooking or processing.
- Segregate flooded and non-flooded crops using buffer zones (e.g. 9 meters as recommended by the US FDA) to minimise the risk of cross-contamination.
- Enhance drainage and irrigation infrastructure, maintain strict hygiene during harvesting, processing, and transport, and regularly monitor water and environmental conditions as integral components of a comprehensive food safety strategy.

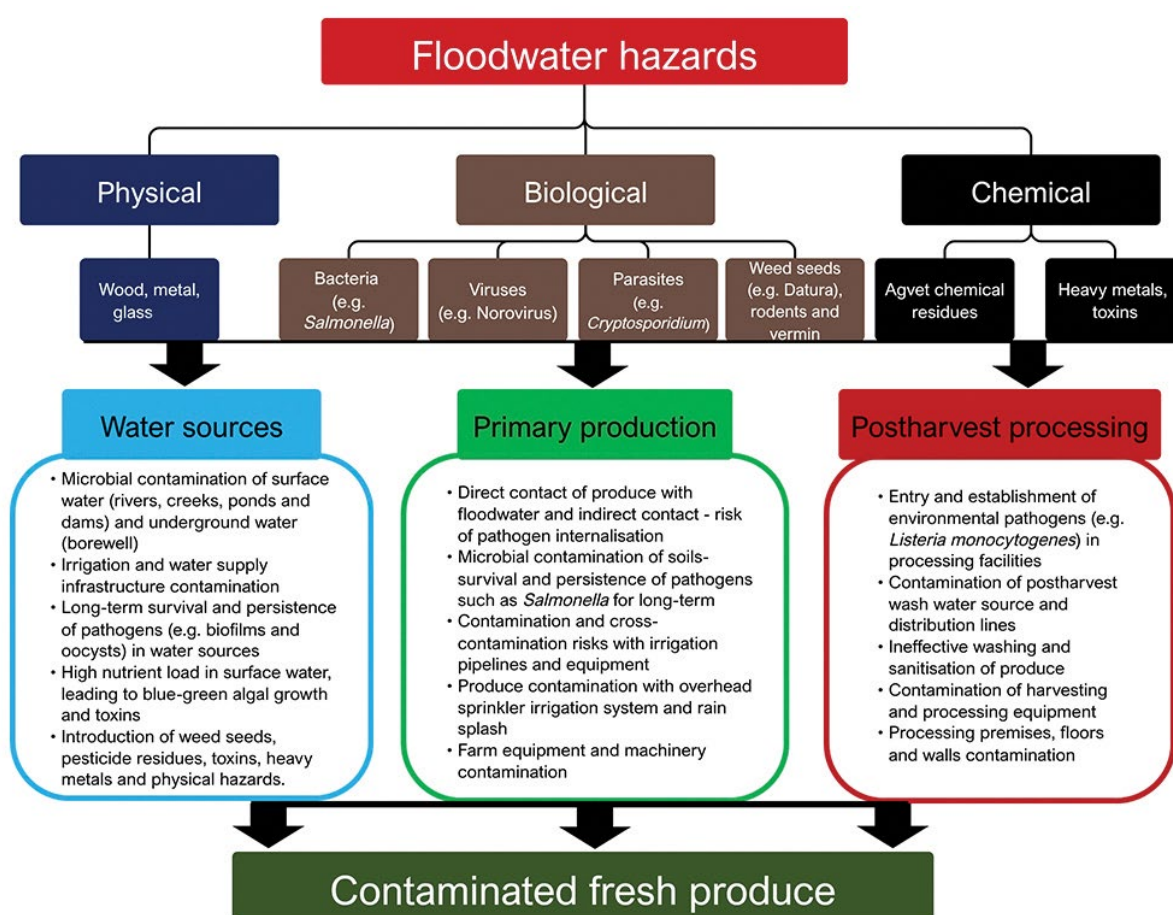


Figure 30. Floodwater as a source and route of microbial contamination in fresh horticultural produce adjacent to livestock, industrial and residential areas (Singh 2023a).

Rainfall

Rainfall intensity can be classified as moderate when precipitation is between 2.5 and 10 mm/hour, and heavy when precipitation exceeds 10 mm/hour. Moderate to heavy rainfall can increase the risk of pathogen contamination in leafy vegetables by splashing and transferring micro-organisms from the soil onto crop surfaces. Where field drainage is inadequate, rainfall can lead to pooling and standing water within the crop, creating conditions that favour pathogen survival and spread. Contamination can occur directly through rainfall splash and indirectly by harvesting machinery moving in wet fields (Figure 31).



Figure 31. Conducting agronomic operations in wet conditions can cause splash mud onto standing crops, increasing the risk of microbial contamination after rainfall.

Following rainfall, particularly in heavy clay soil, machinery is more likely to accumulate mud, and harvested produce might carry a higher organic load and associated microbial contamination. Therefore, moderate to heavy rainfall should be recorded as part of farm food safety records. Harvest decisions should allow as much time as practical for fields and crops to dry before harvest operations start (Figure 32). Attention should also be given to the cleanliness and hygiene of harvesting equipment and machinery. Furthermore, post-harvest washing and processing procedures should be reviewed and adjusted to compensate for the increased organic and microbial load associated with produce harvested after moderate or heavy rainfall. Processors should also be informed through consignment documentation or delivery notes when produce has been harvested following significant rainfall so that appropriate mitigation measures can be implemented.

- Record all moderate and heavy rainfall in farm records.
- Assess fields for water pooling, flooding, and drainage issues before harvest.
- Delay harvest (where possible) to allow crops and fields to dry.
- Inspect crops for visible soil contamination and excess moisture.
- Thoroughly clean and sanitise harvesting equipment and machinery before use.
- Remove mud and organic matter from machinery operating in wet fields.
- Minimise machinery movement in wet areas to reduce soil splash and cross-contamination.
- Increase monitoring of harvested produce for soil contamination and organic load (Figure 33).
- Review and adjust post-harvest washing, sanitising, and processing procedures to account for increased contamination risks. Verify that wash water quality and sanitiser concentrations are maintained at effective levels.
- Communicate the occurrence of moderate or heavy rainfall to processors through consignment notes or delivery documentation. Advise processors that produce might have elevated organic and microbial loads so that appropriate receiving and processing controls can be applied.



Figure 32. Harvesting in wet conditions can result in increased soil contamination of machinery and produce, increasing food safety risks.



Figure 33. Wet harvesting conditions can increase soil and organic matter on produce, increasing contamination risks.

Bushfires

Bushfires have devastating ecological consequences, destroying natural habitats and forcing wildlife, including kangaroos and other marsupials, feral pigs, deer and rodents, into agricultural areas in search of food, water, and shelter. Their presence in fresh produce fields not only damages crops but also introduces biological hazards. Animal faeces can carry foodborne pathogens, which are capable of surviving in soil, water, and on produce for extended periods. The survival and persistence of these pathogens are influenced by environmental factors, including soil type, moisture, temperature, sunlight, and the animal species involved.

Heat-stressed wildlife fleeing bushfire zones are often drawn to surface water sources such as farm ponds and dams. When animals defaecate in or near these water sources, they can introduce microbial contamination, which might be transferred to crops through irrigation or the application of chemical sprays. Additionally, heat-stress conditions can increase pathogen shedding, elevating the risk of contamination compared to normal environmental conditions.

Foodborne pathogens from animal faeces can contaminate crops directly or indirectly via soil, and they might be spread further through rain splash, sprinkler irrigation, or wind. Once crops are contaminated, pathogens can persist throughout harvesting, washing, and post-harvest handling, ultimately posing a risk to consumers. Agricultural water sources such as ponds and dams can act as ongoing reservoirs of pathogens if wildlife defecate in or near them, while post-harvest operations, including wash water, equipment, and processing facilities, can facilitate further spread.

Bushfire risk management strategies

- Mitigating microbial risks requires proactive measures, including regular field monitoring, pre-harvest inspections, and establishing buffer zones around contaminated areas.
- Physical barriers such as fencing or netting can reduce wildlife access to crops and water sources. Staff should be trained to identify contamination and avoid affected produce.
- When faeces are discovered in the field or have directly contacted the produce, harvesting in that area should be avoided. Identify and mark areas with affected produce, and refrain from harvesting in these buffer zones, which could have a radius of between 1 and 10 meters depending upon the crop, production system and animal type. The California Leafy Green Marketing Agreement recommends a minimum of 1.5 m (5 feet) radius of buffer zone for leafy greens.
- Contaminated harvest bins, equipment, and processing facilities should be thoroughly cleaned and sanitised, and water and produce should be microbiologically tested.
- Deposition of ash on leafy vegetables following a bushfire should be assessed, as ash might contain heavy metals, fire suppressant chemicals, and other toxic compounds that could pose food safety risks.
- A co-management approach is recommended, balancing wildlife and environmental conservation with measures to minimise biological hazards, ensuring the safety and quality of fresh produce while maintaining ecological stewardship.





Premises and equipment

Premises

Packing sheds and processing facilities should be designed, constructed and maintained to minimise the risk of leafy vegetables being contaminated by microbial, chemical and physical hazards. Facilities should be located and operated in a manner that reduces exposure to contamination sources such as livestock operations, manure storage areas, waste water systems, flood-prone zones, dust-generating activities and pest harbourage sites.

The surrounding grounds should be maintained in a clean and orderly condition, with effective drainage systems to prevent standing water, run-off accumulation and attracting pests. Premises should be adequately fenced and managed to prevent the entry of livestock, wildlife and reptiles, as these animals can be reservoirs and vectors of microbial contaminants, including foodborne pathogens. Buildings should be designed to facilitate hygienic operations, including adequate separation between harvested produce handling areas, washing and processing operations, finished produce storage and waste handling activities. Traffic for personnel, equipment and produce movement should be managed to minimise opportunities for cross-contamination.

Packing sheds and processing facilities should be constructed using materials that are durable, smooth, impervious and easily cleaned. Floors, walls, ceilings, doors and drainage systems should be maintained in good repair and designed to prevent dirt, moisture and organic matter from accumulating. Adequate lighting and ventilation should be provided for hygienic operations and effective cleaning.

Facilities should be protected from pests, birds, wildlife and reptiles with appropriate exclusion measures such as fencing, sealed building structures, screened openings and regular maintenance. Findings from the Safe Leafy Veg program demonstrated that microbial pathogens could become established within the packing and processing environment, with floors and drains identified as common sites of pathogen detection. In some cases, the same pathogens detected within processing premises were also detected in production fields, indicating potential transfer between the field and facility.

While contaminated produce can introduce micro-organisms into processing facilities, moving machinery and equipment from production fields into packing sheds appears to be a major contributor to pathogen transfer, particularly when tyres and undercarriages are contaminated with soil and mud. This risk is especially significant in leafy vegetable production regions characterised by heavy soil, where machinery can transport substantial quantities of soil into the processing environment in wet conditions. Procedures should therefore be implemented to minimise the transfer of soil into premises through designated traffic routes, vehicle and

equipment cleaning programs, wheel-washing stations, and routine cleaning and sanitising floors and drains.

A documented cleaning, sanitising and maintenance program should be implemented to ensure that all premises remain in a condition suitable for producing leafy vegetables that are safe for human consumption.





Equipment

Equipment used for harvesting, cooling, washing, processing, packing, storing and transporting leafy vegetables should be designed, installed and maintained to prevent produce from being contaminated. Produce-contact surfaces (Figure 34) should be constructed from non-toxic, corrosion-resistant materials and designed to allow effective cleaning, inspection and sanitation. Equipment should be free from cracks, corrosion, damaged surfaces and other defects that might harbour micro-organisms or impede cleaning. Preventive maintenance programs should be applied to ensure equipment remains in a hygienic operating condition and does not become a source of contamination.



Figure 34. Produce contact surfaces, such as conveyor belts, should be smooth and maintained in a clean and sanitised condition.

Harvesting operations involve a wide range of tools, equipment and containers that come into direct contact with leafy vegetables and therefore can be sources and transfer pathways for microbial contamination. Research has identified numerous crop-contact surfaces that can facilitate the transfer of human pathogens during harvest, including harvesting machinery, cutting knives, conveyor belts, cutting boards, harvest bins, cartons and cleaning equipment

(Leaman et al. 2023). If these surfaces become contaminated by contact with soil, water, wildlife, workers or contaminated produce, pathogens can be transferred to harvested crops and subsequently disseminated throughout a production block. Environmental conditions can further influence contamination risks, with several studies showing pathogen transfer is more likely when soil is wet. After rainfall, irrigation or flooding, soil readily adheres to harvesting equipment, tyres, conveyor belts, knives and harvest containers, increasing the potential for contamination of food-contact surfaces and harvested produce.

Maintaining harvesting equipment in a hygienic condition presents unique challenges because harvesting occurs in a dynamic outdoor environment (Figure 35) where speed and efficiency are critical. Soil, plant debris and moisture can accumulate on produce-contact surfaces, equipment frames, conveyor systems, harvest knives, bins and difficult-to-clean areas such as hollow structures, joints and damaged welds. Once contaminated, these surfaces can facilitate the transfer of pathogens to the harvested produce.



Figure 35. Produce contact surfaces on harvesting bins should be cleaned and sanitised before each use to minimise the risk of contamination and cross-contamination.

Harvesting equipment should be regarded as a critical control point for managing microbial risks during production. Best practices include routine cleaning and sanitising produce-contact surfaces and adjacent areas, with particular attention given to harvest knives, conveyor belts, harvest bins and other equipment that frequently contacts produce. Cleaning should focus on removing soil and organic matter before applying sanitiser, as organic residues can significantly reduce sanitiser efficacy and protect micro-organisms from inactivation. Written standard operating procedures for sanitation should clearly describe cleaning frequency, methods, chemicals, equipment disassembly requirements and verification activities.

Particular attention should also be given to equipment used in washing and processing operations, including flumes, wash tanks, conveyors (Figure 36), spray systems, centrifuges and packing lines. These should be routinely cleaned and sanitised to prevent biofilms from developing and organic matter from accumulating, facilitating pathogen survival and cross-contamination. Conveyor belts require special consideration because belt joints, rollers, bearings and inaccessible surfaces can provide harbourage sites for micro-organisms. Equipment used to monitor critical food safety parameters, such as thermometers, sanitiser dosing systems, pH meters and water quality monitoring devices, should be calibrated and verified at defined intervals. Cleaning, maintenance, calibration and verification activities should be documented

and retained as part of the food safety management system. Although improvements in equipment design and hygienic engineering continue to enhance the ease of cleaning, preventing contamination combined with robust cleaning and sanitising programs remains the most effective strategy for minimising microbial risks associated with harvesting and processing equipment.

The Safe Leafy Veg program team found foodborne pathogens on both field equipment and in packing and processing facilities; however, pathogen detections were generally more frequent in the latter. This shows that packing sheds and processing facilities are harbourage and amplification sites for microbial contaminants once pathogens are introduced from the field through produce, personnel, equipment, harvest bins or machinery. Floors, drains and other wet processing areas were common locations for pathogen detections, highlighting the importance of effective sanitation programs and environmental monitoring. Moving machinery, harvest aids and bins from production fields into packing and processing facilities can transfer soil, organic matter and associated micro-organisms, particularly in production regions with heavy clay soil and during wet weather.



Figure 36. Environmental swabbing of harvesting equipment to verify the effectiveness of cleaning and sanitising.

Cleaning and sanitising

Cleaning and sanitising are distinct but complementary processes. **Cleaning** involves removing soil, plant debris, organic matter and other contaminants (Figure 37) by a combination of mechanical action, water, detergents and appropriate contact time. **Sanitising** follows cleaning and is intended to reduce microbial populations on equipment surfaces to acceptable levels.

Numerous studies have shown that surface cleanliness is one of the most important factors influencing sanitiser efficacy (Leaman et al. 2023). Even small amounts of soil, plant residues or crop exudates can protect bacteria from sanitiser action, reduce the effectiveness of antimicrobial treatments and promote the formation of microbial biofilms. Foodborne pathogens of significance to the leafy vegetable industry can survive on harvesting equipment and produce contact surfaces when cleaning is inadequate. Harvesting knives, conveyor belts, cutting boards, harvest bins and other crop-contact surfaces are potential reservoirs and transfer points for pathogens during harvesting operations. Studies have further demonstrated that wet field conditions following rainfall or irrigation can increase the transfer of pathogens through contaminated soil adhering to equipment, tyres and harvest aids. The complete removal of visible contamination should always precede sanitiser application. Cleaning methods involving brushing, scrubbing and detergent-based foaming systems are generally more effective than water-only spray cleaning, particularly on heavily soiled surfaces and equipment exposed to field conditions.



Figure 37. Removing plant debris and organic matter from processing equipment during cleaning is essential to ensure effective sanitising and reducing the risk of microbial contamination.

The effectiveness of sanitising programs depends on several factors, including sanitiser concentration, contact time, temperature, treatment frequency and the condition of the equipment surface. Research has consistently shown that *Listeria monocytogenes* can attach to stainless steel, plastic, rubber and conveyor belt materials and form biofilms that are difficult to remove using standard sanitation procedures. A range of sanitisers, including chlorine-based products, peracetic acid, quaternary ammonium compounds and other approved food-contact sanitisers can be used, provided they are applied according to label directions and food safety requirements. However, no sanitiser can compensate for inadequate cleaning. Therefore,

harvesting and processing operations should implement documented sanitation standard operating procedures (SSOPs) that clearly specify cleaning methods, chemicals, equipment disassembly requirements, sanitiser concentrations, contact times and verification activities.

Regularly validating and verifying cleaning and sanitising procedures by inspections, adenosine triphosphate (ATP) monitoring, environmental swabbing and microbiological testing are necessary to ensure equipment remains free from excessive microbial contamination and does not become a source of cross-contamination during leafy vegetable production and processing.

- Machine harvesters used for baby leaf crops should be thoroughly cleaned and sanitised after each harvesting shift and whenever contamination is suspected (Figure 38).



Figure 38. Deep cleaning and sanitising all parts of harvesting equipment, including hard-to-reach places, are critical for reducing contamination risks.

- Produce-contact surfaces on harvesting equipment, including conveyor belts and harvesting knives, should be routinely inspected, cleaned and sanitised to prevent soil, plant residues and microbial contaminants from accumulating.
- Conveyor belts and harvesting knives can contribute to microbial biofilm formation if organic matter is allowed to accumulate. Effective cleaning procedures should therefore focus on completely removing soil and plant debris before applying a sanitiser.
- Harvest bins, crates (Figure 39) and other produce containers are major hotspots for cross-contamination. They should be cleaned and sanitised (Figure 40 and Figure 41) after each use and before being returned to the field for harvest operations.
- Cutting knives, trimming knives and chopping equipment used during field harvesting or in packing sheds should be cleaned and sanitised at defined intervals.
- Equipment should be inspected regularly for damaged surfaces, cracks, worn conveyor belts, damaged welds and hollow structures that might harbour micro-organisms and impede effective cleaning.
- Harvesting machinery operating in wet fields can transfer and splash mud, soil and contaminated water onto standing crops. Where possible, harvesting should be delayed until field conditions improve, particularly following heavy rainfall or irrigation that results in standing water.

- Tyres, tracks, undercarriages and other non-food contact surfaces on harvesting machinery should be cleaned as necessary to minimise the movement of soil and associated microbial contaminants from one field to another and from production fields into packing and processing facilities.
- The effectiveness of harvesting and processing equipment cleaning and sanitising programs should be verified through documented inspections and, where appropriate, ATP monitoring, environmental swabbing or microbiological testing.
- Vacuum cooling systems should be included in the documented cleaning and sanitising program. Vacuum chambers and associated equipment should be routinely cleaned and sanitised to prevent microbial contaminants from accumulating and spreading.



Figure 39. Harvest crates and other produce containers are major hotspots for cross-contamination.



Figure 40. An automated unit for cleaning and sanitising harvest crates.

- Water, if used in hydro-vacuum cooling systems, should be drinking water quality and contain <1 cfu of generic *E. coli* per 100 mL.
- Wash tanks, flumes and associated water distribution systems should be cleaned and sanitised at a frequency sufficient to prevent organic matter, biofilms and microbial contaminants from accumulating.
- Conveyor belts used during washing, processing and packing operations should be routinely cleaned and sanitised to remove leaf debris, soil and moisture that can support microbial growth. Belt joints, rollers, bearings, return surfaces and other difficult-to-clean areas should receive special attention.
- Cool rooms and associated equipment should be routinely cleaned and sanitised to prevent environmental pathogens from establishing and persisting. Particular attention should be given to floors, drains, evaporator units, cooling coils, condensate drip trays, walls, doors and other areas prone to accumulating moisture.
- Environmental pathogens such as *Listeria monocytogenes* can survive and persist in cool, moist conditions and might establish harbourage sites if cleaning and sanitation programs are inadequate. Routine environmental monitoring, particularly in high-risk processing and storage areas, should be considered to verify the effectiveness of sanitation programs.



Figure 41. A project team member collecting microbiological swabs from plastic crates.





Temperature of harvested leafy vegetables

Controlling the temperature of leafy vegetables is one of the most important post-harvest practices for maintaining their safety, quality and shelf life. After harvest, leafy vegetables continue to respire and rapidly lose moisture, resulting in wilting, quality deterioration and reduced shelf life. Elevated temperatures can also promote the growth of spoilage micro-organisms and, where conditions permit, human pathogens. Rapidly removing field heat and maintaining the cool chain are therefore essential to minimise microbial risks and preserve produce quality.

Vacuum cooling is the most widely used method in the leafy vegetable industry because it efficiently removes field heat from large volumes of produce in a short period ([Figure 42](#)). However, many small and medium-sized leafy vegetable businesses do not have access to vacuum cooling facilities due to cost and infrastructure limitations. Alternative cooling methods and good temperature management practices become even more important to ensure produce is cooled as quickly as possible after harvest ([Figure 43](#)).



Figure 42. Vacuum cooling is the most common pre-cooling method in the leafy vegetable industry.



Figure 43. A cold storage facility used for cooling of harvested produce on a small-scale farm.

- Harvest leafy vegetables during the coolest times of the day and minimise the time between harvest and cooling. Harvested produce should be protected from direct sunlight (Figure 44) using shade cloth, covered trailers or other suitable methods while awaiting transport or processing.



Figure 44. Produce should not be left out in the sun.

- Remove field heat as rapidly as possible using vacuum cooling, hydro-cooling, forced-air cooling, refrigerated storage or other suitable cooling systems. Where vacuum cooling is unavailable, alternative cooling strategies should be used to achieve rapid temperature reduction.
- Water used for hydro-cooling or vacuum cooling should be drinking water quality and routinely monitored to ensure it does not become a source of microbial contamination.
- Maintain the cool chain throughout washing, processing, packing, storage, transport and distribution (Figure 45).
- Washed and packed leafy vegetables should generally be maintained between 2 °C and 4 °C to minimise microbial growth, preserve quality and extend shelf life.
- Refrigeration equipment, vacuum cooling systems and cool rooms should be routinely maintained, monitored, cleaned and sanitised to ensure efficient operation and to minimise the persistence of pathogens such as *Listeria monocytogenes* in a cool, moist environment.



Figure 45. The cold chain (2–4 °C) should be maintained during all post-harvest stages to minimise food safety risks.





Washing and sanitising harvested leafy vegetables

Washing and sanitising are critical components of leafy vegetable (e.g. baby leaf category) processing and play an important role in maintaining produce safety, quality and shelf life. The primary purpose is to remove soil, plant debris and nutrient-rich exudates released from cut leaves during harvesting and post-harvest handling. If poorly managed, wash water can spread contamination from dirty produce to clean produce. Adding sanitisers to wash water is essential for controlling microbial contamination and minimising cross-contamination during processing. Sanitisers are primarily intended to inactivate micro-organisms in the wash water rather than to sanitise the leafy vegetables themselves. In addition to sanitising wash water, effective concentrations of sanitiser, along with contact time, also reduce microbial load on the produce surface. Inadequate sanitiser concentrations, high organic loads and poor wash water management can rapidly reduce sanitiser efficacy and increase cross-contamination risks. Therefore, sanitiser concentrations, contact times, pH, turbidity and organic load should be routinely monitored and managed to ensure the washing system remains effective.

- Multi-stage washing systems incorporating pre-washing and double or triple washing steps are considered best practice for leafy vegetable processing. The data from the Safe Leafy Veg program showed that triple washing was more effective in reducing microbial load on spinach and rocket leaves than double washing. Although triple washing can better improve microbial quality, it might also increase tissue damage due to the more vigorous washing and agitation involved. Therefore, depending on the commodity, a balance should be achieved between improving microbial quality and minimising physical damage.
- A pre-wash rinse is an important first step in leafy vegetable processing. It is designed to remove most of the soil, plant debris and other organic matter from harvested produce before it enters the main washing and sanitising system. As a result, an effective pre-wash rinse improves the efficiency of washing and sanitising systems, reduces water and sanitiser demand, and minimises cross-contamination risks.
- Water used for washing and sanitising leafy vegetables should be drinking water quality and contain <1 cfu of generic *E. coli* per 100 mL. Water should be monitored at the point of use to verify that it remains suitable throughout processing ([Figure 46](#)).



Figure 46. Post-harvest wash water quality is a critical factor determining microbial food safety outcomes.

- Wash water should contain an approved sanitiser to minimise the transfer and accumulation of micro-organisms during processing.
- Sanitiser concentrations and contact times should be maintained at validated levels throughout processing.
- Industrial-scale studies have shown the minimum effective concentration of sanitisers in process wash water varies depending on the type of fresh produce being washed and the operational conditions of the washing system.
 - For chlorine-based sanitising systems, research suggests that free chlorine concentrations of approximately 10 ppm might be sufficient to control cross-contamination in some leafy vegetable processing operations. However, other studies have shown that higher concentrations, typically in the range of 20–25 ppm free chlorine, are required to achieve effective microbial control and maintain adequate sanitiser residuals under commercial processing conditions, particularly where organic loads are elevated (Gombas et al. 2017; Tudela et al. 2019).
 - Peracetic acid (PAA) is commonly used in leafy vegetable processing because it remains effective in a broad pH range and in higher organic loading conditions than chlorine. Typical operating concentrations range from 50 to 150 ppm, depending on the process design, produce type and manufacturer recommendations.
- Automated dosing and monitoring systems are recommended to maintain consistent sanitiser performance and minimise operator error. Continuously monitoring free chlorine or peracetic acid concentrations, pH, oxidation-reduction potential (ORP), temperature and water turbidity can help ensure critical operating limits are maintained.
- Multi-stage washing systems should be designed to progressively remove soil, organic matter and microbial contaminants. Pre-wash systems should remove most of the dirt and organic material before produce enters the sanitised wash tanks, thereby reducing sanitiser demand and improving overall wash water efficacy. The cleanest water and highest sanitiser efficacy should be maintained in the final wash and sanitising stages.

- High produce-to-water ratios can cause rapid accumulation of soil, plant debris, leaf exudates and micro-organisms in the wash water, leading to increased sanitiser demand and reduced disinfection efficacy. Conversely, lower produce-to-water ratios generally improve washing efficiency by providing greater dilution of contaminants and reducing the rate at which water quality deteriorates ([Figure 47](#)).



Figure 47. Adequate water-to-produce ratios during washing help maintain wash water quality and reduce the risk of microbial cross-contamination.

- Wash water should be replenished continuously or at defined intervals to maintain water quality and prevent soil, plant debris, organic matter and micro-organisms from accumulating. Water replacement rates should be based on produce throughput, organic loading, turbidity, sanitiser demand and microbial risk.
- Washing and sanitising processes should be adjusted to compensate for the increased organic load and microbial contamination associated with extreme weather ([Figure 48](#)). Effective cleaning and sanitising of processing equipment are critical to prevent pathogen-containing biofilms from forming and foodborne pathogens from persisting in the processing environment ([Figure 49](#)).
- Owing to the diversity of leafy vegetable commodities, post-harvest washing practices differ among crop types. Leafy herbs are commonly subjected to batch washing ([Figure 50](#)), whereas some farms spray-wash head crops (e.g. lettuce and Chinese cabbage) either in the field or at processing facilities ([Figure 51](#)). Where washing is undertaken, potable-quality water supplemented with an effective sanitiser should be used to minimise the risk of cross-contamination and maintain the microbiological quality of the wash water.



Figure 48. Accumulation of residual soil and organic matter at the bottom of a wash-water tank following the harvest of baby leaf after heavy rainfall.



Figure 49. Effective cleaning is essential for removing soil, organic matter, and plant debris before sanitising, ensuring the efficacy of sanitisers and reducing the risk of microbial contamination.



Figure 50. Washing and sanitising harvested herbs by immersion in crates, illustrating both the washing process and the diversity of leafy vegetable crops.



Figure 51. Spray washing Chinese cabbage (wombok) on a conveyor belt before packing.





Animals and pests

Animals and pests can introduce foodborne pathogens into leafy vegetable production and processing systems through faeces, urine, nesting materials and direct contact with produce, water sources, equipment and produce-contact surfaces. Livestock, wildlife, birds, rodents, reptiles and insects have all been identified as potential reservoirs or vectors of pathogens such as *Listeria monocytogenes*, *Salmonella* spp. and Shiga toxin-producing *Escherichia coli* (STEC). Preventing animals and pests from accessing leafy vegetable production and processing areas is therefore essential to minimise contamination risks.

- Regularly assess the risks associated with animals and pests in production fields, water sources, buildings, equipment and surrounding areas.
- Routinely look for evidence of animal activity, including faeces, tracks, burrows, digging, nests, feathers, crop damage and signs of rodent or insect infestations.
- Protect and maintain growing sites to discourage animals and pests using fencing, exclusion barriers and good site maintenance practices.
- Minimise potential attractants by controlling weeds and vegetation, eliminating standing water, and promptly removing produce waste, cull piles and other organic materials that might provide food or shelter for pests.
- Regularly monitor crops for animal intrusion, with particular attention immediately before harvest when contamination is most likely to affect produce.
- Where evidence of animal activity, faecal contamination or carcasses is observed, assess the affected area and determine whether produce can be harvested safely or whether exclusion zones should be established.
- Grazing livestock on leafy vegetable fields immediately after harvest should be avoided if the next crop is to be planted within a short period. Grazing animals deposit faeces directly onto the soil surface, introducing foodborne pathogens.
- Where grazing has occurred, an appropriate withholding period should be observed before planting the next leafy vegetable crop, and the potential risk should be assessed as part of the farm's food safety management program.
- Establish and maintain appropriate buffer zones between leafy vegetable production areas and potential contamination sources, such as livestock operations, grazing land, feedlots, manure storage areas, composting sites and wildlife habitats.
- Where practical, vegetative windbreaks, shelterbelts or physical barriers should be used with fencing to reduce the movement of dust, aerosols, run-off, wildlife and other contaminants into production areas.
- The width and design of buffer zones should be based on a site-specific risk assessment that considers topography, prevailing wind, adjacent land use, drainage patterns and the potential for pathogen movement from nearby contamination sources.

- Monitor water sources for animal activity and implement corrective actions where livestock, wildlife or birds might compromise water quality (Figure 52 and Figure 53).
- Ensure buildings, packing sheds, cool rooms and processing facilities are designed and maintained to prevent birds, rodents, insects and other pests entering through doors, windows, vents and other openings.
- Implement a documented pest management program that includes routine monitoring, inspection, corrective actions and record keeping.
- Use approved bait stations, traps and other pest control measures in accordance with manufacturer instructions and regulatory requirements, ensuring they do not contaminate produce, packaging materials, equipment or food-contact surfaces.
- Train personnel to recognise signs of animal intrusion and pest activity and to report contamination that might affect produce safety.



Figure 52. Water birds on a farm pond.



Figure 53. Waterbird activity around an irrigation dam, showing faecal contamination on the dam liner, which is a potential source of biological hazards.



Skills and knowledge

Personnel involved in producing, harvesting, packing, processing, storing and transporting leafy vegetables should have food safety and food hygiene knowledge and skills appropriate to the tasks they perform. **Food hygiene** refers to the practices and conditions used to prevent contamination of leafy vegetables, including personal hygiene, equipment sanitation, water quality management, pest control and cross-contamination prevention (Figure 54). **Food safety** is achieved when these practices are effectively implemented to ensure leafy vegetables remain safe for consumption.

Knowledge refers to an individual's understanding of food safety hazards and how their activities might affect the safety of leafy vegetables. **Skills** refer to the ability to perform tasks correctly and consistently in a manner that protects food safety. For example, harvest workers should understand the risks associated with animal intrusion and faecal contamination and be able to identify and report affected areas to supervisors. Personnel responsible for washing and processing operations should understand the importance of water quality, sanitiser concentrations and process monitoring and be competent in applying and verifying these controls. The method used to obtain food safety knowledge and skills might vary according to the size and complexity of the business and does not necessarily require formal training courses.

- Identify all activities undertaken by the business that might affect the safety of leafy vegetables and use this information to determine training needs. Process flow diagrams can help identify food safety risks and training requirements.
- Clearly define the food safety responsibilities of employees, supervisors, contractors and visitors and ensure personnel understand the food safety risks associated with their duties.
- Provide food safety and hygiene training appropriate to each employee's role, including personal hygiene, preventing contamination, sanitising equipment, managing water, handling produce, pest control and reporting food safety concerns.
- Train personnel to identify, report and respond to conditions that might compromise food safety, including animal intrusion, faecal contamination, pest activity, poor water quality, equipment failures, foreign material contamination and the presence of toxic weeds.
- Deliver training through appropriate methods such as in-house programs, mentoring by experienced staff, formal courses, online learning programs, consultant-led training, industry workshops and toolbox meetings.
- Ensure employees have access to relevant food safety procedures, work instructions, grower guides and standard operating procedures (SOPs) and that these documents are understood and consistently followed.
- Display signs, posters, photographs and visual aids in appropriate work areas to reinforce food safety and hygiene practices and remind personnel of their responsibilities.

- Verify employee competency through observation (Figure 55), supervision, assessments or other suitable methods and provide additional training where knowledge or skill gaps are identified.
- Provide induction training for new employees and refresher training at regular intervals, particularly before harvest seasons, when procedures change, following food safety incidents or when deficiencies are identified.
- Promote a positive food safety culture where employees are encouraged to follow procedures, ask questions, report concerns and actively contribute to continuous improvement in food safety practices.
- Maintain records of training, competency assessments, refresher programs and food safety communication as part of the food safety management system.



Figure 54. Personnel wearing appropriate personal protective equipment (PPE), including protective clothing, hair coverings, and other required hygiene apparel, before entering a high-care processing environment. Proper use of PPE is essential to minimise contamination risks and ensure produce safety.



Figure 55. Have trained personnel to monitor and manage potential food safety hazards introduced while mechanically harvesting baby leaf vegetables.

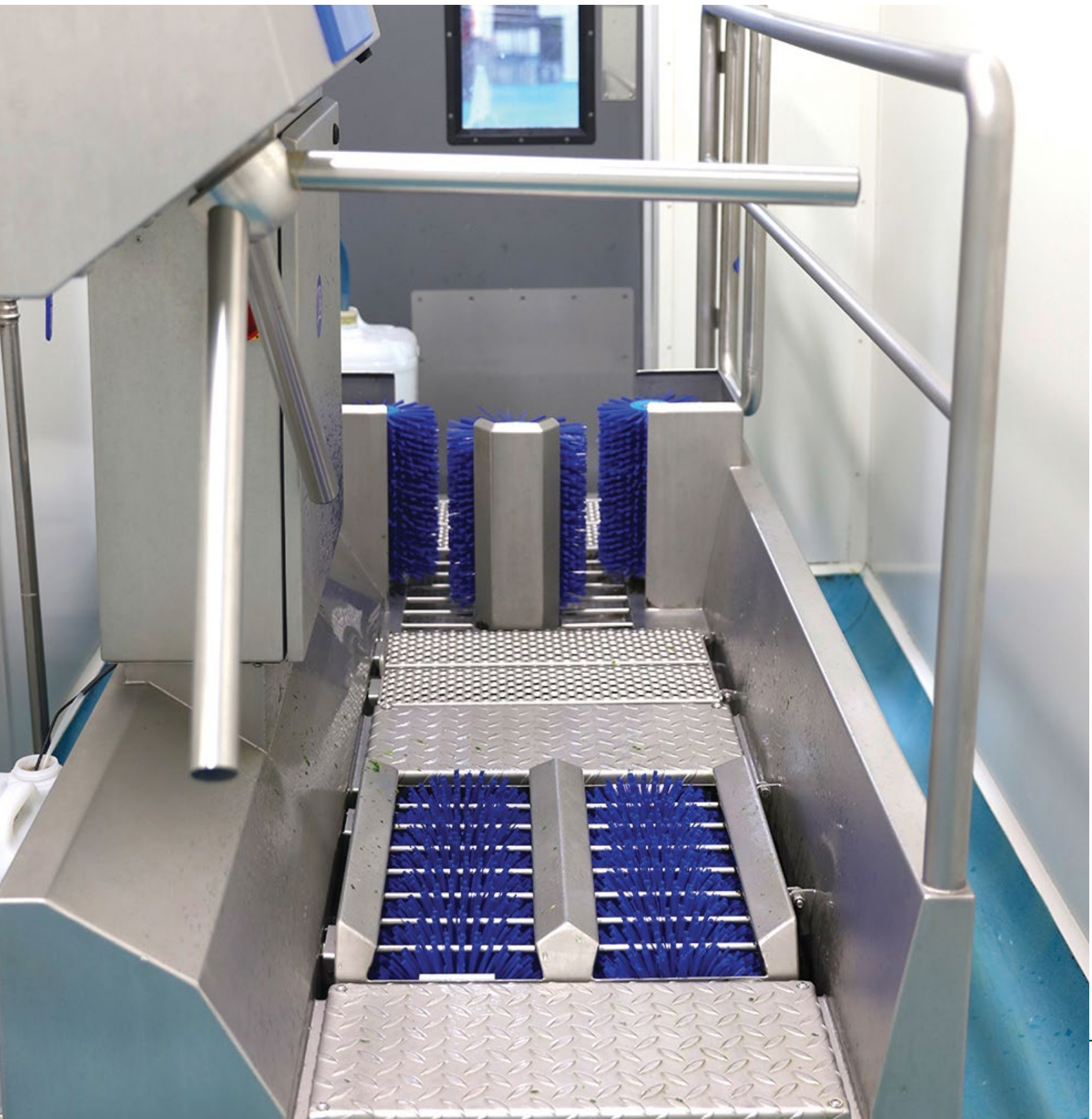


Health and hygiene of personnel and visitors

Personnel and visitors can be a significant source of contamination in leafy vegetable production and processing operations. Human pathogens might be transferred to produce through contaminated hands, clothing, footwear, personal items, equipment or poor hygiene practices. Illnesses such as gastroenteritis and respiratory infections can increase the risk of contamination, particularly during harvesting, packing and processing activities, where produce is handled directly. Businesses should therefore establish and maintain health and hygiene practices that minimise the risk of contamination and ensure all personnel and visitors understand and comply with these requirements.

- Develop and implement documented personal hygiene procedures that apply to employees, contractors, visitors and other persons entering production, packing or processing areas.
- Ensure personnel understand the importance of personal hygiene and their role in preventing contamination of leafy vegetables.
- Provide clean, accessible and adequately supplied toilet and handwashing facilities in convenient locations for workers in the production fields and processing facilities.
- Require personnel to wash their hands before starting work, after using the toilet, eating, drinking or smoking, handling contaminated materials, contact with animals, and whenever hands become dirty or might have become contaminated.
- Ensure handwashing facilities are supplied with potable water, soap, single-use paper towels or other hygienic drying methods, and waste disposal facilities.
- Encourage employees to immediately report illnesses, injuries or conditions that might affect food safety, particularly gastrointestinal illnesses, diarrhoea, vomiting, fever, respiratory infections or infected wounds.
- Exclude personnel with gastrointestinal illness from handling leafy vegetables or food-contact surfaces until they are fit to return to work.
- Consider assigning recovering employees to low-risk duties that do not involve direct contact with produce, food contact surfaces or processing equipment.
- Require personnel working in packing and processing areas to wear clean clothing and suitable protective garments such as gloves, aprons, hair coverings, beard covers, face masks and protective footwear. Ensure jewellery, personal items and loose objects are controlled in processing and packing areas to minimise contamination risks.

- Provide food safety, personal hygiene and illness reporting training during employee induction and at regular intervals thereafter, particularly before each harvest or processing season.
- Provide visitors with information on site hygiene requirements before entering production, packing or processing areas and ensure they are supervised.
- Consider implementing visitor health declarations or screening procedures to minimise the risk of introducing illness into the production or processing environment.
- Display signs, posters and visual reminders in relevant locations to reinforce handwashing, personal hygiene, illness reporting and other food safety practices.
- Maintain records of hygiene training, visitor inductions, illness reports and corrective actions as part of the food safety management system.





Sale or supply of unacceptable leafy vegetables

Leafy vegetables should be produced, harvested, packed, processed, stored and transported in a way that ensures they remain safe and suitable for human consumption. A business must not sell or supply leafy vegetables if it knows, or has reasonable grounds to suspect, the produce is unsafe or unsuitable for human consumption.

Unacceptable leafy vegetables include produce that might be a food safety risk, has been contaminated, is deteriorated, or does not meet intended food safety and suitability requirements. Businesses should establish procedures for identifying, segregating, investigating and disposing of unacceptable produce to prevent it from entering the food supply chain.

Examples of unacceptable leafy vegetables includes any that have been:

- directly contacted or submerged by floodwater, where the edible portions have been exposed to potentially contaminated water
- contaminated by fuels, lubricants, pesticides, cleaning chemicals or other hazardous substances because of spills, leaks or accidental exposure
- contaminated by soil, mud, insects, spiders, frogs, animal faeces or other foreign material that indicates inadequate cleaning or contamination
- affected by significant animal intrusion, faecal contamination or carcasses where food safety cannot be assured
- exposed to contaminated water, untreated waste, sewage or other sources of microbiological contamination
- exposed to poor temperature control, excessive spoilage, decay or decomposition and are no longer suitable for human consumption
- associated with a food safety incident, adverse microbiological test results, contamination or traceability investigation indicating the produce might be a risk to consumers.

Businesses are responsible for implementing and maintaining controls throughout the production and supply chain to manage food safety and quality risks by:

- implementing monitoring and verification activities throughout production and processing to identify unacceptable produce before it enters the market
- establishing procedures for segregating, identifying and disposing of produce that might be unsafe or unsuitable

- investigating contamination, equipment failures, water quality issues, temperature deviations or other incidents that might affect produce safety
- maintaining traceability and record-keeping systems that enable affected produce to be identified, isolated and managed quickly
- where there is uncertainty regarding the safety or suitability of some produce, adopting a precautionary approach and withhold it from sale until its acceptability can be determined.





Managing food safety risks associated with toxic weeds in leafy vegetables

The [Australia New Zealand Food Standards Code](#) requires food producers to ensure their products are safe and suitable for sale and consumption.

In 2022, a foodborne illness outbreak caused by ingestion of a toxic weed in baby spinach products occurred and is an example of a food safety risk that might not be familiar to producers and others in the produce supply chain.

Baby spinach and other products containing spinach, supplied by a single farm were recalled, with many people suffering serious health effects after consuming toxic weeds. The health effects were consistent with the ingestion of a toxic weed, *Datura stramonium* (commonly known as thornapple or jimson weed; [Figure 56](#) to [Figure 59](#)). This weed was found in produce supplied to supermarkets and on the source farm.

Toxic weeds in leafy vegetables

Weeds are an integral risk associated with leafy vegetable production in open fields. Some weeds such as *Datura* spp., *Atropa belladonna* (deadly nightshade) and *Hyoscyamus niger* (common henbane) are toxic due to the accumulation of tropane alkaloids (TA) in their leaves, stems, flowers and fruit. Tropane alkaloids are secondary plant metabolites that are distributed in many other species of the genera such as *Solanum*, *Mandragora*, *Brugmansia*, *Duboisia*, and *Scopolia*.

Although over 200 TAs are known, atropine, hyoscyamine and scopolamine are the main alkaloids found in TA-producing plants. The concentration of hyoscyamine in the analysed samples is usually expressed as 'atropine', which is the racemic mixture of (-)-hyoscyamine and (+)-hyoscyamine. Growing season conditions, geographical location, plant maturity, plant species and variety, and type of plant tissue can all affect the concentration and proportion of hyoscyamine and scopolamine in plants (FAO and WHO 2020). These alkaloids are relatively heat-stable and can withstand harvesting, processing and food preparation. If ingested, TA can cause poisoning with adverse health effects, such as anticholinergic syndrome, hallucinations, palpitations, disorientation, dry mucous membranes, skin redness, pupil dilation, dizziness and impaired vision.



Figure 56. *Datura stramonium* foliage. Photo: Bruce Ackley, The Ohio State University, Bugwood.org.



Figure 57. *Datura stramonium* foliage. Photo: Lynn Sosnoskie, University of Georgia, Bugwood.org.



Figure 58. *Datura stramonium* flower. Photo: Lynn Sosnoskie, University of Georgia, Bugwood.org.



Figure 59. *Datura stramonium*. Photo: Jan Samanek, Phytosanitary Administration, Bugwood.org.

Foodborne illness intoxication incidents linked to tropane alkaloids

Internationally, there are several reported intoxication outbreaks linked to TA-contaminated food products.

- In March–April 2019, a large-scale food poisoning outbreak affecting more than 300 people, including 5 deaths, was linked to jimson weed (*Datura stramonium*) contamination of a fortified corn-soy blend distributed in the Republic of Uganda. This was the largest documented outbreak caused by food contamination with TA (Mutebi et al. 2022).
- In July 2020, a family in France mistakenly cooked and consumed jimson weed leaves (*Datura stramonium*) and suffered food poisoning (ANSES 2020).
- In March 2021, frozen spinach puree contaminated with TA affected over 100 people in Slovakia and the Czech Republic (Plackova et al. 2022). The outbreak was attributed to *Datura stramonium* growing with spinach in the field as a weed and contaminated the spinach due to insufficient controls.

Potential causes/sources and routes of contamination with toxic weeds or weed seeds

The industry uses a range of weed control methods as part of integrated weed management to minimise the economic losses caused by these unwanted plants. Despite all the advances in weed management, it remains a challenge to control weeds in the leafy vegetable production system. Several factors limit weed management strategies, including:

- Spinach is a fast-growing, short-duration crop (30 to 50 days). Several herbicides have a longer withholding period and do not fit into the weed management system. This could limit producers' ability to undertake effective weed control.
- There are limited pre-and post-emergent herbicide options to manage a variety of weeds.
- Post-emergent selective herbicides might not include the entire weed spectrum.
- Herbicide application and efficacy are affected by rainfall and other factors. Excessive rainfall during the early stages of planting and growth could decrease the efficacy of pre- and post-emergent herbicides.
- Weeds can emerge from below the applied band of pre-emergent herbicide.
- Contaminated seed could spread toxic weeds in the production field.
- Some weeds are hard-seeded and plants will continue to emerge over many years, regardless of the level of management used.
- The production field could be infested with toxic weed seed from the previous crop.
- Adverse weather such as flooding, run-off and dust storms can transfer weed seeds to leafy vegetable fields.
- Agronomic practices such as deep tillage could bring the viable weed seed to the topsoil layer. Improper (lower) planting density can provide more space for weeds to grow and compete with the crop.
- Toxic weeds at early growth stages (leaves and stems) could be difficult to distinguish from some crops and can be mixed with leaves during harvest or processing.
- Labour shortages and costs associated with manual weed control methods.

Management options

- Understand the weed spectrum in the production fields and identify the risks associated with toxic weeds in the production fields and adjacent blocks.
- The production site should be prepared and remediated before each crop, ensuring integrated weed management practices are incorporated.
- Use weed-free seed to prevent the spread of weeds in the field and minimise the risks.
- Agronomic practices such as crop rotation, planting/sowing density, tillage, and fertigation should be implemented to achieve optimum weed control.
- Selection of pre- and post-emergent herbicides capable of targeting toxic weeds should be part of the weed control strategy.
- Laser weeding is an emerging technology for effective, non-chemical weed control and is likely to be used more in leafy vegetable production.
- The most important strategy is to visually inspect the fields throughout the cropping cycle, especially immediately before the harvesting decision is made.
- Producers should train field workers to identify problematic toxic weeds and report them to the harvest crew manager or supervisor.
- Processors should train and educate workers to report any unusual weeds or leaves in the processing line.

The most important strategy is to visually inspect the fields throughout the cropping cycle, especially immediately before the harvesting decision is made (Figure 60).



Figure 60. Pre-harvest inspection to identify and assess potential food safety hazards, including toxic weeds, wildlife intrusion, animal activity, and other sources of contamination.





Microbiological testing

Microbiological testing is an important verification tool to help producers and processors assess the effectiveness of food safety controls and identify potential sources of contamination. Testing produce, water, soil and environmental samples should be done as part of routine verification activities or in response to elevated food safety risks. However, microbiological testing should not be relied upon as the sole food safety control measure.

Testing represents only a snapshot in time, and results should be interpreted in conjunction with risk assessments, production practices, environmental conditions and other monitoring activities. As microbiological testing can be costly and resource-intensive, testing programs should be risk-based and targeted towards situations where contamination risks are elevated.

Produce testing

Produce testing should be considered where leafy vegetables are:

- irrigated using overhead sprinkler systems supplied with water containing elevated levels of *E. coli* (e.g. >100 cfu/100 mL)
- grown in soil amended with untreated or partially treated animal manure
- produced near livestock operations or other potential sources of faecal contamination
- grown on land where livestock grazing has occurred before planting
- associated with a food safety incident, produce complaint, pathogen detection or recall investigation
- exposed to extreme weather such as flooding, heavy rainfall, dust storms or cyclones.

Pre-harvest produce testing

Modelling conducted by Reyes et al. (2023) showed that produce testing is most effective when done before post-harvest interventions such as washing and sanitising, as contamination in the field might be diluted or masked by subsequent processing steps. Pre-harvest testing, therefore, provides producers with an opportunity to identify potential food safety risks before harvest (Figure 61). However, pre-harvest testing should not replace good agricultural practices or other preventive controls and should be used as part of a broader food safety management program.



Figure 61. Pre-harvest testing enables producers to identify potential food safety risks before harvest and make informed decisions regarding harvest timing and produce use.

Routine pre-harvest testing is generally not necessary for all crops but might be considered where contamination risks are elevated. Risk-based testing might be particularly appropriate following severe weather, flooding, cyclones, animal intrusion, irrigation water quality failures, food safety incidents, pathogen detections, produce recalls or outbreak investigations. Producers seeking to implement pre-harvest testing programs might refer to the guidance developed by the California Leafy Greens Marketing Agreement (LGMA), which provides detailed protocols for risk-based sampling and testing of leafy vegetables.

Research has shown that low-level and sporadically distributed contamination within leafy vegetable fields can be difficult to detect using conventional sampling approaches. Studies by Quintanilla Portillo et al. (2022) demonstrated that the likelihood of detecting contamination increases as the total composite sample mass increases and when samples are collected from a larger number of locations throughout the production area.

Pre-harvest testing programs are generally more effective when they involve collecting a greater number of smaller samples distributed in the field using a randomised or systematic sampling approach. This strategy improves field representation and increases the probability of detecting low-level contamination that might otherwise be missed if only a small number of large samples are collected. An example of a risk-based pre-harvest sampling plan adapted from the California Leafy Greens Marketing Agreement (LGMA) is provided in [Table 3](#).

Table 3. An example of a sampling plan adapted from the California Leafy Greens Handler Marketing Agreement (LGMA).

Crop examples	Total sample size per acre (g)	Sub-sample size (g)	Number of sub-samples per acre	Number of grab specimens per sample	Grab specimen size (g)
Baby leaf (e.g. spinach, rocket)	1,500	150	10	60	2.5
Romaine and iceberg lettuce, cabbage	1,500	375	4	15	25

For baby leaf crops, a total composite sample mass of 1,500 g might be obtained by collecting 10 sub-samples of 150 g from the production area. For head-forming crops such as iceberg and romaine lettuce, 4 sub-samples of 375 g might be collected to achieve the same total sample mass. Grab specimens should be collected from multiple plants throughout the field to ensure a representative sample (Figure 62). Each sub-sample should be submitted and analysed as a separate test unit.

Laboratories doing pathogen testing should use validated methods capable of analysing larger sample masses. The objective is to maximise the probability of detecting low-level contamination that might be missed using traditional 25 g analytical portions. Where testing is conducted, all sample material collected as part of the sampling plan should be included within the laboratory testing program.



Figure 62. Collecting representative produce samples using appropriate hygiene practices, including the use of disposable gloves to minimise the risk of sample contamination.

Natural disasters and flood-affected crops

Leafy vegetables that have been directly contacted, submerged or contaminated by floodwater or significant run-off should not be harvested for human consumption. Floodwater might contain pathogens originating from livestock operations, wildlife, sewage systems, manure storage areas and other contamination sources.

Where flooding has occurred, producers should undertake a documented risk assessment before replanting. Consistent with California LGMA guidance, replanting should generally be delayed for at least 60 days following floodwater exposure. A shorter interval might be considered where a risk assessment and microbiological testing show that soil conditions have recovered and contamination risks have been adequately managed. Any decision to replant should consider flood severity, contamination sources, soil conditions, environmental factors and laboratory results.

Guidance for risk-based pre-harvest testing

- Conduct pre-harvest sampling as close as practical to harvest, preferably within 7 days of the planned harvest date.
- Consider defining sampling units as lots of 0.4 hectares (one acre) or less to improve the representativeness of sampling results.
- Use a systematic sampling approach in the field by dividing the production block into grids and collecting samples from multiple locations throughout each grid.
- Collect samples from the entire production area, including locations considered to be at higher risk of contamination, such as low-lying areas, field edges, locations adjacent to livestock operations or areas affected by run-off.
- Consider a composite sample size of approximately 1,500 g collected from a minimum of 60 individual sampling points within the designated lot.
- Where pathogen testing is undertaken, consider analysis for Shiga toxin-producing *Escherichia coli* (STEC), *Listeria monocytogenes* and *Salmonella* spp. Enumeration of generic *E. coli* might also provide useful information regarding potential faecal contamination.
- Develop documented procedures for managing positive test results, including harvest holds, additional investigations, corrective actions and produce marketing or sale decisions.

Soil testing

Soil testing should be considered in production fields that:

- have been affected by flooding or other extreme weather that might introduce contaminants
- have had animal manure or other organic soil amendments within the previous growing season
- have been grazed by livestock before planting
- are located adjacent to livestock operations or other land uses that might increase contamination risks
- have been associated with previous pathogen detections or contamination.

Three common methods used for soil sampling for microbiological purposes in produce fields are boot swabs, drag swabs, and soil grab samples.

1. **Boot swab sampling** involves placing sterile absorbent covers over boots and walking through the field ([Figure 63](#)) so that soil and any micro-organisms on the soil surface are collected over a large area.
2. **Drag swab sampling** uses a sterile absorbent sponge that is dragged over the soil surface as the sampler walks, allowing contaminants from multiple locations to be collected into a single sample.
3. **Soil grab sampling** involves collecting small amounts of soil directly from the ground using a soil probe, auger, or scoop, usually from a specified depth below the surface. Multiple grab samples are often combined to form a representative composite sample for testing.

While boot swabs and drag swabs are aggregated methods that cover larger areas and are useful for detecting surface contamination, soil grab samples provide information about the conditions and potential contamination in the soil profile.

Boot swabs are widely used in the meat and poultry industries to monitor pathogen indicators in poultry litter and to assess cleaning and sanitising effectiveness. Boot swabs allow the collection of surface-level samples over a larger area as the sampler walks through the field. Recent studies have demonstrated the potential of boot swab sampling as a pre-harvest produce safety tool, showing that aggregate boot cover sampling can outperform traditional high-resolution soil core sampling in detecting microbial contamination in active lettuce fields, even when the swabs are not hydrated.



Figure 63. A soil boot swab by a farm staff member.

Boot and drag swabs hydrated in phosphate-buffered saline and buffered peptone water are potentially a more representative and practical method of soil sampling and monitoring than conventional soil grabs (Kealey et al. 2026, Wu et al. 2023). However, boot swabs might have limitations in very moist or wet soil conditions (Figure 64), where excessive soil adhesion can make sampling difficult, reducing the area that can be effectively sampled. Despite these limitations, boot swab sampling offers an efficient and practical method for enhancing food safety surveillance in fresh produce production systems, particularly in suitable field conditions.



Figure 64. Excessive soil adhesion on boot swabs when sampling wet soil.

Soil testing can be a valuable verification tool where elevated contamination risks have been identified, particularly after flooding, applying animal manure or grazing activities. As contamination might be unevenly distributed throughout a field, sampling programs should be designed to maximise representativeness.

Divide the production block into a grid and conduct systematic sampling throughout the field using a randomised starting point and predetermined sampling intervals.

- For each 0.4 hectare (one acre) of production area, at least 4 sampling locations should be selected to ensure representative coverage of the field. At each location, one boot swab sample is collected by wearing sterile boot swabs and walking approximately 25 metres (20–25 steps) along the crop bed to obtain an aggregated surface soil sample, resulting in a minimum of 4 boot swab samples per 0.4 hectare.
- One composite soil grab sample might be collected from 4 sampling locations per 0.4 hectare (one acre) using a soil probe or scoop to a depth of 100–150 mm. Each composite soil sample should consist of at least 3 sub-samples collected within the sampling area and thoroughly mixed before being placed into a sterile polyethylene bag. The final composite sample should weigh approximately 750 g to 1 kg to provide sufficient material for laboratory analysis.

Together, these sampling approaches provide a representative assessment of both surface and subsurface soil contamination in the field. The number of samples and sub-samples might be increased depending upon site-specific risk assessment needs. Target organisms might include generic *E. coli* count, Shiga toxin-producing *Escherichia coli* (STEC), *Salmonella* spp. and other pathogens relevant to the identified risk.

Irrigation water testing

Water testing should be conducted as part of routine water quality monitoring and should be increased where water sources:

- have been affected by flooding, heavy rainfall or other extreme weather
- are used for overhead irrigation, particularly close to harvest
- have historically elevated levels of generic *E. coli* (e.g. >100 cfu/100 mL)
- are located downstream or adjacent to intensive livestock operations, grazing areas, feedlots or other potential contamination sources
- show evidence of wildlife activity, run-off intrusion or deteriorating water quality.

Microbiological testing of irrigation water should be undertaken to verify water quality and assess the potential risk of contamination of leafy vegetables.

- Collect samples from the point of application, if possible, including sprinklers, emitters or other irrigation outlets, as these represent the water directly contacting the crop.
- Where irrigation systems are used, allow the system to operate for several minutes before sampling to ensure samples are representative of the water source rather than residual water within pipelines.
- Consider collecting samples from locations closest to and furthest from the water source, as well as from primary water sources such as rivers, canals, dams or ponds.
- Additional sampling can be conducted from primary water sources such as rivers, canals and ponds.
- From each location/source, collect at least one litre of water in sterile sampling bottles containing sodium thiosulfate. Proper sample handling is also critical. Containers must be sterile, samples must be cooled immediately after collection, and laboratory analysis must be done within 24 hours to prevent changes in microbial counts between sampling and testing.
- Test water samples for generic *E. coli* as an indicator of faecal contamination and consider pathogen testing where elevated risks have been identified.

Frequency of irrigation water testing

There is no single irrigation water testing frequency that is appropriate for all leafy vegetable operations. The frequency of testing should be determined through a risk assessment that considers the type of water source, method of irrigation, crop susceptibility, adjacent land uses, historical water quality results, seasonal conditions and the likelihood of contamination.

Surface water sources such as rivers, creeks, channels, dams (Figure 65) and ponds are generally more vulnerable to contamination from livestock, wildlife, run-off and extreme weather than groundwater or municipal water supplies, and might therefore require more frequent monitoring. Additional testing should also be considered following flooding, heavy rainfall, prolonged dry periods, water quality failures or other events that might affect water quality.

Producers should review and analyse historical water quality data, ideally over a period of 5–10 years, to identify seasonal trends, spikes and declines in *E. coli* populations and other indicators of contamination. Understanding these patterns can help producers identify periods of elevated risk, assess the effectiveness of mitigation measures and develop risk-based water management strategies. Historical data might also help identify the influence of rainfall, irrigation demand, livestock activity, wildlife pressure and other environmental factors on water quality.



Figure 65. Livestock activity upstream can compromise the microbial quality of irrigation water sources.

As a general guide, large-scale producers (>10 hectares) should test irrigation water monthly during crop production periods. Medium-scale producers (2–10 hectares) should undertake seasonal testing, with a minimum of 4 samples collected annually or at least one sample during each production season. Small-scale producers (<2 hectares) should test irrigation water at least annually during crop production and preferably during periods of greatest risk, such as during summer (December–January). Businesses using high-risk water sources or overhead irrigation systems might need to undertake more frequent testing to verify that water quality remains suitable for its intended use.

- Develop a risk-based microbiological testing program based on water source, production practices, adjacent land uses, environmental conditions and historical testing results.
- Use microbiological testing to verify the effectiveness of food safety controls rather than as a substitute for good agricultural and processing practices.

- Consider additional testing following extreme weather, flooding, contamination incidents, produce recalls or significant changes in production practices.
- Investigate and document positive pathogen detections or elevated indicator organism results and implement corrective actions.
- Review testing data over time to identify trends, emerging risks and opportunities for continuous improvement in food safety management.

Post-harvest water testing

Water quality is critical to the safety of washed and processed leafy vegetables. Water used for washing produce, equipment cleaning, cooling operations and personnel hygiene should be of drinking-water quality and routinely verified.

- Conduct microbiological testing of water used for washing produce, equipment cleaning and handwashing facilities to verify compliance with potable water requirements.
- Monitor wash water sanitiser concentrations, contact times and replenishment rates to ensure effective control of cross-contamination risks.
- Verify automated sanitiser dosing systems through regular manual measurements of sanitiser concentrations and other critical parameters.
- Monitor wash water quality parameters including pH, turbidity, oxidation-reduction potential (ORP), temperature and organic loading to ensure sanitiser efficacy is maintained.
- Consider microbiological testing of wash water and flumes for generic *E. coli* and, where appropriate, foodborne pathogens as part of verification programs designed to assess cross-contamination risks and the effectiveness of wash water management systems.
- Following extreme weather or elevated contamination risks, additional controls such as increased water replacement, enhanced monitoring, and validated adjustments to sanitiser concentrations or contact times might be required.

References

- Allende A and Monaghan J (2015) Irrigation water quality for leafy crops: a perspective of risks and potential solutions. *International Journal of Environmental Research and Public Health*, 12(7): 7457–77, doi:10.3390/ijerph120707457
- ANSES (French Agency for Food, Environmental and Occupational Health and Safety, 2020) Severe poisoning after consumption of toxic jimson weed leaves from a vegetable patch, <https://www.anses.fr/en/content/severe-poisoning-after-consumption-toxic-jimsonweed-leaves-vegetable-patch>, accessed on 18 December 2022.
- Australian and New Zealand Guidelines (ANZG, 2023) Water quality for irrigation and general water uses: background information. Australian and New Zealand Guidelines for fresh and marine water quality: Australian and New Zealand governments and Australian state and territory governments. Commonwealth of Australia, Canberra, 170 pp.
- Californian Leafy Greens Handler Marketing Agreement (LGMA, n.d.) Food safety program, <https://lgma.ca.gov/food-safety-program>, accessed 30 March 2025.
- Castro-Ibáñez I, Gil MI, Tudela JA and Allende A (2015) Microbial safety considerations of flooding in primary production of leafy greens: a case study. *Food Research International*, 68: 62–69, <https://doi.org/10.1016/j.foodres.2014.05.065>
- Cooley MB, Jay-Russell M, Atwill ER, Carychao D, Nguyen K, Quiñones B, Patel R, Walker S, Swimley M, Pierre-Jerome E, Gordus AG and Mandrell RE (2013) Development of a robust method for isolation of Shiga toxin-positive *Escherichia coli* (STEC) from fecal, plant, soil and water samples from a leafy greens production region in California. *PLoS One*, 8(6):e65716, <https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0065716>
- Duffy LL, Small A and Fegan N (2010) Concentration and prevalence of *Escherichia coli* O157 and *Salmonella* serotypes in sheep during slaughter at two Australian abattoirs. *Australian Veterinary Journal*, 88: 399–404.
- Edge T, El-Shaarawi A, Gannon V, Jokinen C, Kent R, Khan I, Koning W, Lapen D, Miller J, Neumann N, Phillips R, Robertson W, Schreier H, Scott A, Shtepani I, Topp E, Wilkes G and Bochove E (2012) Investigation of an *Escherichia coli* environmental benchmark for waterborne pathogens in agricultural watersheds in Canada. *Journal of Environmental Quality*, 41(1): 21–30, <https://access.onlinelibrary.wiley.com/doi/10.2134/jeq2010.0253>
- European Food Safety Authority (EFSA) Biohaz Panel: Koutsoumanis K, Allende A, Alvarez-Ordóñez A, Bover-Cid S, Chemaly M, Davies R, De Cesare A, Herman L, Hilbert F and Lindqvist R (2020) Pathogenicity assessment of Shiga toxin-producing *Escherichia coli* (STEC) and the public health risk posed by contamination of food with STEC. *European Food Safety Authority (EFSA) Journal*, 18(1): 5967, <https://efsa.onlinelibrary.wiley.com/doi/full/10.2903/j.efsa.2020.5967>
- FAO and WHO (2020) Joint FAO/WHO expert meeting on tropane alkaloids, 30 March to 3 April 2020. *Food Safety and Quality Series* No. 11, Rome, <https://openknowledge.fao.org/items/7c366567-8ca0-4fbb-8982-a57feca68ce8>
- Food Standards Australia New Zealand (FSANZ, 2024) Safe horticulture Australia – a guide to the primary production and processing standards for horticulture. Food Standards Australia New Zealand, <https://www.foodstandards.gov.au/sites/default/files/2024-10/Safe%20Horticulture%20Australia%20-%20web.pdf>
- Gombas D, Luo Y, Brennan J, Shergill G, Petran R, Walsh R, Hau H, Khurana K, Zomorodi B, Rosen J, Varley R and Deng K (2017) Guidelines to validate control of cross-contamination during washing of fresh-cut leafy vegetables. *Journal of Food Protection*, 80: 312–330, doi:10.4315/0362-028X.JFP-16-258
- Gyles CL (2007) Shiga toxin-producing *Escherichia coli*: an overview. *Journal of Animal Science*, 85: E45–E62.
- Holvoet K, Samplers I, Seynnaeve M and Uyttendaele M (2014) Relationships among hygiene indicators and enteric pathogens in irrigation water, soil and lettuce and the impact of climatic conditions on contamination in the lettuce primary production. *International Journal of Food Microbiology*, 171: 21–31, doi:10.1016/j.ijfoodmicro.2013.11.009
- Ilic S, Moodispaw MR, Madden LV and Lewis Ivey ML (2022) Lettuce contamination and survival of *Salmonella typhimurium* and *Listeria monocytogenes* in hydroponic nutrient film technique systems. *Foods*, 11(21): 3508, <https://doi.org/10.3390/foods11213508>
- Ingle DJ, Gonçalves da Silva A, Valcanis M, Ballard SA, Seemann T, Jennison AV, Bastian I, Wise R, Kirk MD, Howden BP and Williamson DA (2019) Emergence and divergence of major lineages of Shiga-toxin-producing *Escherichia coli* in Australia. *Microbial Genomics*, 5(5): e000268.

- Jablasone J, Warriner K and Griffiths M (2005) Interactions of *Escherichia coli* O157:H7, *Salmonella typhimurium* and *Listeria monocytogenes* in plants cultivated in a gnotobiotic system. *International Journal of Food Microbiology*, 99 (1): 7–18, <https://doi.org/10.1016/J.IJFOODMICRO.2004.06.011>
- Kealey E, Elementi R, Frankowski Z, Valizadegan N, Barnett-Neefs C, Wu J, Banerjee P and Stasiewicz MJ (2026) Validating aggregate soil sampling using bootie and drag swabs hydrated with simple wetting agents in commercial produce fields. *Microbiology Spectrum*, 14(3): e0166325, <https://journals.asm.org/doi/10.1128/spectrum.01663-25>
- Leaman SM, Kerr J, Salas S, Malik A, Suslow TV, Wiedmann M and Davis DA (2023) Fresh produce harvesting equipment – a review of cleaning and sanitizing practices and related science. *Food Protection Trends*, 43(2): 126–143.
- Liu D, Cui Y, Walcott R and Chen J (2017) Fate of *Salmonella enterica* and enterohemorrhagic *Escherichia coli* cells artificially internalized into vegetable seeds during germination. *Applied and Environmental Microbiology*, 84(1): e01888-17, <https://doi.org/10.1128/AEM.01888-17>
- Mellor GE, Fegan N, Duffy LL, McMillan KE, Jordan D and Barlow RS (2016) National survey of Shiga toxin-producing *Escherichia coli* serotypes O26, O45, O103, O111, O121, O145, and O157 in Australian beef cattle feces. *Journal of Food Protection*, 79: 1868–1874.
- Mutebi RR, Ario AR, Nabatanzi M, Kyamwine IB, Wibabara Y, Muwerezza P, Eurien D, Kwesiga B, Bulage L, Kabwama SN and Kadobera D (2022) Large outbreak of jimson weed (*Datura stramonium*) poisoning due to consumption of contaminated humanitarian relief food: Uganda, March–April 2019. *BMC Public Health*, 22(1): 1–10, <https://pubmed.ncbi.nlm.nih.gov/35354446/>
- National Notifiable Diseases Surveillance System (NNDSS, 2025) National communicable disease surveillance dashboard, <https://www.health.gov.au/resources/publications/national-communicable-disease-surveillance-dashboard-user-guide>, accessed 30 March 2025.
- New South Wales Department of Planning and Environment (2023) Quantitative microbial risk assessment of adenovirus and *Ascaris* in FOGO and GO compost. State of NSW, Sydney.
- New South Wales Environment Protection Authority (2016) The compost order, <https://www.epa.nsw.gov.au/sites/default/files/rro16-compost.pdf>
- Obayomi O, Bernstein N, Edelstein M, Vonshak A, Ghazayarn L, Ben-Hur M, Tebbe C and Gillor O (2019) Importance of soil texture to the fate of pathogens introduced by irrigation with treated wastewater. *The Science of the Total Environment*, 653, 886–896, <https://doi.org/10.1016/j.scitotenv.2018.10.378>
- Ongeng D, Geeraerd AH, Springael D, Ryckeboer J, Muyanja C and Mauriello G (2015) Fate of *Escherichia coli* O157:H7 and *Salmonella enterica* in the manure-amended soil-plant ecosystem of fresh vegetable crops: a review. *Critical Reviews in Microbiology*, 41: 273–294.
- Persad AK and LeJeune JT (2014) Animal reservoirs of Shiga toxin-producing *Escherichia coli*. *Microbiology Spectrum*, 2: 10.1128, <https://journals.asm.org/doi/10.1128/microbiolspec.ehec-0027-2014>
- Plackova S, Caganova B, Otrubova O, Puchon E and Batora I (2022) Anticholinergic poisoning associated with frozen spinach. *Clinical Toxicology*, 60 (S1): 30.
- ProMED-mail (2019) Program for monitoring emerging diseases. International Society for Infectious Diseases (ISID). Contaminated spinach – Turkey: nightshade suspected, <https://www.promedmail.org/>
- Quintanilla Portillo J, Cheng X, Belias AM, Weller DL, Wiedmann M and Stasiewicz MJ (2022) A validated pre-harvest sampling simulation shows that sampling plans with a larger number of randomly located samples perform better than typical sampling plans in detecting representative point-source and widespread hazards in leafy green fields. *Applied and Environmental Microbiology*, 88(23): e0101522.
- Raudales RE, Parke JL, Guy CL, Fisher PR (2014) Control of waterborne microbes in irrigation: a review. *Agricultural Water Management*, 143: 9–28, <https://doi.org/10.1016/j.agwat.2014.06.007>
- Reyes GA, Quintanilla Portillo J and Stasiewicz MJ (2023) Leafy green farm-to-customer process model predicts product testing is most effective at detecting contamination when conducted early in the system before effective interventions. *Applied and Environmental Microbiology*, 89(5): e0034723.
- Riggio GM, Jones, SL and Gibson KE (2019) Risk of human pathogen internalization in leafy vegetables during lab-scale hydroponic cultivation. *Horticulturae*, 5: 25, <https://doi.org/10.3390/horticulturae5010025>
- Seaton F, George P, Lebron I, Jones D, Creer S and Robinson D (2020) Soil textural heterogeneity impacts bacterial but not fungal diversity. *Soil Biology and Biochemistry*, 144: 107766, <https://doi.org/10.1016/j.soilbio.2020.107766>

- Shelton DR, Karns JS, Coppock C, Patel J, Sharma M and Pachepsky YA (2011) Relationship between eae and stx virulence genes and *Escherichia coli* in an agricultural watershed: implications for irrigation water standards and leafy green commodities. *Journal of Food Protection*, 74(1): 18–23, <https://pubmed.ncbi.nlm.nih.gov/21219758/>
- Singh SP (2023a) Flooding adversely affects fresh produce safety. *Microbiology Australia*, 44: 185–189.
- Singh SP (2023b) Microbial food safety risks associated with producing and processing fresh produce in bushfire-affected regions, *Primefact* 23/1247, NSW Department of Primary Industries and Regional Development (DPIRD), first edition, https://www.dpiird.nsw.gov.au/__data/assets/pdf_file/0007/1500928/Microbial-food-safety-risks-associated-with-producing-and-processing-fresh-produce-in-bushfire-affected-regions.pdf
- Singh SP (2025) The Safe Leafy Veg project provides insights into microbial risks and their management. AusVeg Knowledge Hub, <https://ausveg.com.au/knowledge-hub/the-safe-leafy-veg-project-provides-insights-into-microbial-risks-and-their-management/>
- Singh SP, Shadbolt C, Cusack D and Turner M (2025) ‘Mind the W’: bridging gaps in the production and supply of safe leafy vegetables. *Food Australia*, 77 (4): 29–32.
- Topalcengiz Z, Chandran S and Gibson KE (2024) A comprehensive examination of microbial hazards and risks during indoor soil-less leafy green production. *International Journal of Food Microbiology*, 411: 110546, <https://doi.org/10.1016/j.ijfoodmicro.2023.110546>
- Topalcengiz Z, Strawn LK and Danyluk MD (2017) Microbial quality of agricultural water in Central Florida. *PLoS ONE*, 12(4): e0174889, <https://doi.org/10.1371/journal.pone.0174889>
- Tudela JA, López-Gálvez F, Allende A and Gil MI (2019) Chlorination management in commercial fresh produce processing lines. *Food Control*, 106: 106760, <https://doi.org/10.1016/j.foodcont.2019.106760>
- Uhlig A, Kjellström N, Nurminen C, Olsson E, Oscarsson P, Canaviri-Paz L, Mogren L, Alsanius B, Molin G and Håkansson Å (2021) Use of bacterial strains antagonistic to *Escherichia coli* for biocontrol of spinach: a field trial. *Innovative Food Science & Emerging Technologies*, 74: 102862, <https://doi.org/10.1016/j.ijfoodmicro.2023.110546>
- United States Department of Agriculture (USDA, 2012) Risk profile for pathogenic non-O157 Shiga toxin-producing *Escherichia coli* (non-O157 STEC). Office of Public Health Science. Office of Policy and Program Development. Food Safety and Inspection Service.
- Vally H, Hall G, Dyda A, Raupach J, Knope K, Combs B and Desmarchelier P (2012) Epidemiology of Shiga toxin-producing *Escherichia coli* in Australia, 2000–2010. *BMC Public Health*, 12: 63, <https://doi.org/10.1186/1471-2458-12-63>
- Van Der Linden I, Cottyn B, Uyttendaele M, Vlaemynck G, Maes M and Heyndrickx M (2013) Long-term survival of *Escherichia coli* O157:H7 and *Salmonella enterica* on butterhead lettuce seeds, and their subsequent survival and growth on the seedlings. *International Journal of Food Microbiology*, 161 (3): 214–219, <https://doi.org/10.1016/j.ijfoodmicro.2012.12.015>
- Vasant BR, Stafford RJ, Jennison AV, Bennett SM, Bell RJ, Doyle CJ, Young JR, Vlack SA, Titmus P, El Saadi D, Jarvinen KAJ, Coward P, Barrett J, Staples M, Graham RMA, Smith HV and Lambert SB (2017) Mild illness during outbreak of Shiga toxin-producing *Escherichia coli* O157 infections associated with agricultural show, Australia. *Emerging Infectious Diseases*, 23: 1686–1689.
- Victorian Environment Protection Authority (2021) EPA determination – specifications acceptable to the authority for receiving processed organics. *Victoria Government Gazette* No. S 723, <https://www.gazette.vic.gov.au/gazette/Gazettes2021/GG2021S723.pdf>
- Wilkinson K, Smith J, Biala J, Lee-Steere C and Boxshall A (2024) *A critical assessment of standards and the supply chain for producing high-quality recycled organic products*. Department of Climate Change, Energy, the Environment and Water. Commonwealth of Australia.
- Wu J, Gathman RJ, Portillo JQ, Gaulke C, Kim M and Stasiewicz MJ (2023) Aggregative soil sampling using boot covers compared to soil grabs from commercial romaine fields shows similar indicator organism and microbial community recoveries. *Journal of Food Protection*, 86(11): 100177.
- Xia Q, Rufty T and Shi W (2020) Soil microbial diversity and composition: links to soil texture and associated properties. *Soil Biology and Biochemistry*, 149: 107953, <https://doi.org/10.1016/j.soilbio.2020.107953>

Appendix I

State and Territory food regulatory agencies – contact details and enquiry types

State/Territory	Agency	Contact details	Enquiry Type
ACT	ACT Health Protection Service	Phone: (02) 5124 9700 Website: www.health.act.gov.au	Food business registration, inspections, food complaints, foodborne illness investigations and enforcement.
NSW	NSW Food Authority	Phone: (02) 9741 4780 Website: www.foodauthority.nsw.gov.au	Food safety regulation, primary production, horticulture, processing, food recalls, audits, licensing, food complaints, traceability, enforcement and compliance activities.
NT	Northern Territory Department of Health – Environmental Health Program	Phone: (08) 8922 7497 Website: health.nt.gov.au	Food safety regulation, food business compliance, food complaints, foodborne illness investigations and food premises inspections.
QLD	Queensland Health	Phone: (07) 3328 9310 Website: www.qld.gov.au/health	Food manufacturing, food standards compliance, food complaints, food recalls, foodborne illness investigations and enforcement.
QLD	Safe Food Production Queensland (SFPQ)	Phone: (07) 3253 9800 Website: www.safefood.qld.gov.au	Accreditation and regulation of primary production sectors including horticulture.
SA	SA Health – Food and Controlled Drugs Branch	Phone: (08) 8226 7100 Website: www.sahealth.sa.gov.au	Food safety regulation, food recalls, food complaints, foodborne illness investigations, food incidents and compliance activities.
SA	PIRSA Food Safety and Regulation	Phone: (08) 8429 0837 Email: pirsa.foodsafety@sa.gov.au Website: www.pir.sa.gov.au	Primary production, food safety and horticulture.
TAS	Department of Health – Food Safety Unit	Phone: 1800 671 738 Email: public.health@health.tas.gov.au Website: www.health.tas.gov.au	Food legislation, food business compliance, food complaints and food incidents.
TAS	Department of Natural Resources and Environment, Tasmania	Phone: (03) 6233 8011 Website: nre.tas.gov.au	Food safety licensing, audits and primary production food safety horticulture.
VIC	Agriculture Victoria*	Website: https://agriculture.vic.gov.au/biosecurity/food-safety	Primary production food safety programs for horticulture, on-farm food safety, biosecurity and agricultural food safety enquiries.
VIC	Department of Health – Food Safety Unit	Phone: 1300 364 352 Email: foodsafety@health.vic.gov.au Website: www.health.vic.gov.au/foodsafety	General food safety legislation, food business compliance, retail food regulation, food incidents and policy guidance.
WA	Department of Health – Environmental Health Directorate	Website: www.health.wa.gov.au	Food legislation, food safety regulation, food incidents, food complaints and public health food safety matters.
WA	Local Government Environmental Health Services	Local council contacts	Food business registration, inspections, food premises approvals, food complaints and retail food regulation.

* The Victorian Government is establishing a new regulator, Safe Food Victoria, to deliver food safety regulation by merging functions from Agriculture Victoria, Dairy Food Safety Vic and PrimeSafe.

National agencies

Agency	Contact details	Enquiry Type
Food Standards Australia New Zealand (FSANZ)	Phone: (02) 6271 2222 Website: www.foodstandards.gov.au	Australia New Zealand Food Standards Code, food standards development, food recalls, food labelling, food composition and regulatory policy.
Department of Agriculture, Fisheries and Forestry (DAFF)	Website: www.agriculture.gov.au	Imported food inspection, export certification, export registered establishments, market access and imported food compliance.

Appendix 2

Food safety management statement template

Introduction

A food safety management system (FSMS) is a document that describes a leafy vegetable producer or processor's activities and operational practices. The document should:

- Describe the identification, assessment and management of food safety risks that might arise during the production, harvesting, post-harvest handling, processing, storage and distribution of leafy vegetables.
- Specify the preventive controls, monitoring procedures, corrective actions, verification activities and record-keeping systems implemented to ensure that identified risks are effectively controlled and reduced to an acceptable level.

Where a grower or processor operates multiple growing and processing sites, a site-specific FSMS should be developed and maintained for each location. While some policies and procedures might be applied at multiple sites, site-specific hazards, operational practices, infrastructure, environmental conditions and risk control measures should be identified, assessed, documented, and managed separately for each site.

Businesses that operate under a recognised Global Food Safety Initiative (GFSI) certification scheme, such as Freshcare, Safe Quality Food (SQF) or other equivalent programs, may not require a separate FSMS. However, this template can be used as a supplementary tool to support the periodic review of food safety hazards, risk assessments, control measures and risk management practices within the business.

This template has been developed to help leafy vegetable producers and processors meet the requirements of **Standard 4.2.8** of the **Australia New Zealand Food Standards Code**. This template is intended as a guide only and does not replace any regulatory obligations that may apply under state or territory legislation. State and territory food regulatory agencies have developed their own FSMS templates and guidance documents to help businesses meet jurisdiction-specific regulatory requirements. Producers are encouraged to consult the relevant food regulatory authority to ensure compliance with local requirements.

The Microsoft Word template of the FSMS may be requested from Dr S.P. Singh, sp.singh@dpiird.nsw.gov.au

Checklist instruction: please read each item carefully and tick (✓) all options that apply, except where otherwise indicated.

Section 1. Business information and scope of operations

Complete the following information for each site and the activities covered by the FSMS.

1.1 Business details

Business name: _____

Trading name (if applicable): _____

ABN/ACN: _____

Business address: _____

Postal address (if different): _____

Contact person: _____

Phone number: _____

Email address: _____

Emergency contact (optional): _____

Emergency contact phone number (optional): _____

1.2 Person responsible for the FSMS

Name: _____

Position/title: _____

Qualifications and/or food safety training completed: _____

Contact details: _____

1.3 Food safety certification

1.3.1 Is the business currently certified under a Global Food Safety Initiative (GFSI) recognised scheme?

☐ No

☐ Yes (complete the details below)

Food safety scheme (e.g. Freshcare): _____

Certificate number: _____

Expiry date: _____

1.3.2 Scope of certification

Select the leafy vegetables (e.g. lettuce, spinach, cabbage) covered by the certification:

☐ Primary production (growing) only

☐ Processing only

☐ Primary production and processing

☐ Other (specify): _____

1.3.3 Certification body details

Certification body: _____

Date of most recent audit: _____

Outcome of most recent audit: _____

Any other certifications: e.g. organic _____

1.4 What types of leafy vegetables are produced, processed or supplied

List all leafy vegetables covered by this FSMS.

Product 1 (e.g. Iceberg lettuce)

Product name/variety: _____

Growing area (ha): _____

Estimated annual production (tonnes): _____

Product 2 (e.g. spring onion)

Product name/variety: _____

Growing area (ha): _____

Estimated annual production (tonnes): _____

Product 3 (e.g. baby spinach)

Product name/variety: _____

Growing area (ha): _____

Estimated annual production (tonnes): _____

Total production area under leafy vegetables (ha): _____

Total annual production volume of leafy vegetables (tonnes): _____

1.5 What production system(s) are used

- ☐ Organic production system
- ☐ Conventional or integrated production system
- ☐ Soil-based production in open fields
- ☐ Soil-based production under cover (partially enclosed structures)
- ☐ Soil-based production under cover (fully enclosed structures)
- ☐ Soil-less production (e.g. hydroponic) in an open environment
- ☐ Soil-less production (e.g. hydroponic) under cover (partially enclosed structures)
- ☐ Soil-less production (e.g. hydroponic) under cover (fully enclosed structures)
- ☐ Intensive vertical farming
- ☐ Aquaponic production
- ☐ Nursery or seedling production
- ☐ Other (please specify): _____

1.6 What production and processing sites are used

Provide details for all production, harvesting, packing, storage and processing sites covered by this FSMS.

Site name: _____

Property address: _____

Lot/DP number or property identifier: _____

Activities conducted:

- ☐ Growing
- ☐ Harvesting
- ☐ Packing

- ☐ Storage
- ☐ Processing
- ☐ Distribution
- ☐ Other: _____

1.7 What types of customers does the business supply

Indicate the types of customers supplied by the business.

- ☐ Wholesalers (or market agents)
- ☐ Processors
- ☐ Retailers
- ☐ Food service businesses
- ☐ Restaurants and cafés
- ☐ Export markets
- ☐ Direct-to-consumer sales
- ☐ Other (specify): _____

1.8 What business activities are covered by this FSMS

Tick all activities undertaken by the business.

1.8.1 Production activities

- ☐ Growing
- ☐ Harvesting

1.8.2 Post-harvest activities

- ☐ Field packing
- ☐ Trimming and cutting
- ☐ Washing
- ☐ Washing and sanitising
- ☐ Cooling
- ☐ Cold storage
- ☐ Packing
- ☐ Repacking
- ☐ Storage
- ☐ Distribution
- ☐ Transport
- ☐ Other post-harvest handling activities (specify): _____

1.9 Additional information

Provide any additional information relevant to the scope of operations covered by this FSMS.

Section 2. Traceability, product identification and recall

This section documents the systems and records used to trace leafy vegetables and major inputs through the supply chain, facilitate produce recalls and manage customer complaints.

2.1 Can all leafy vegetables grown, processed, packed, stored or supplied by your business be traced back to the production site and traced forward to the next recipient in the supply chain?

- ☐ Yes
- ☐ No

2.2 Produce identification and traceability methods

How do you ensure that all leafy vegetables sold or supplied by your business can be traced back to where they were grown, harvested, packed or processed?

- ☐ Batch codes
- ☐ Harvest date codes
- ☐ Production site identifiers
- ☐ Colour coding systems
- ☐ Produce stickers or labels
- ☐ Barcodes or QR codes
- ☐ Sales receipts
- ☐ Dispatch records
- ☐ Harvest records
- ☐ Farm notebooks or field logbooks
- ☐ Packing records
- ☐ Electronic traceability software. If yes, specify:
- ☐ Other (specify): _____

2.3 Traceability records

Do you maintain traceability records?

- ☐ Yes – digital records
- ☐ Yes – paper-based records
- ☐ Combination of digital and paper-based records
- ☐ No

Describe the traceability system used by the business: _____

2.4 Digital traceability performance

How quickly can you identify the recipient(s) of a specific batch or consignment of leafy vegetables?

- ☐ Within 1 hour
- ☐ Within 4 hours
- ☐ Within 24 hours
- ☐ Within 2–3 business days
- ☐ Not applicable

Date of last traceability exercise or mock recall: _____

Outcome of exercise: _____

2.5 Produce recall

Does your business have a documented produce recall and withdrawal procedure?

☐ Yes

☐ No

Does your business maintain records of customer complaints relating to food safety?

☐ Yes

☐ No

2.6 Recall/withdrawal coordinator

Name: _____

Position/title: _____

Contact details: _____

Section 3. Management of inputs

3.1 Water

3.1.1 Identify all water sources used for irrigation, agricultural chemical application, fertigation, produce washing, cooling, cleaning or other activities

☐ River, creek, stream

☐ Bore or groundwater

☐ Spring or soak water

☐ Farm pond sourced from river/creek/stream

☐ Farm pond sourced from river and borewell

☐ Farm pond sourced from borewell

☐ Potable water (town water or mains supply)

☐ Rainwater

☐ Recycled or reclaimed water (e.g. Class A)

☐ Other (specify): _____

3.1.2 Identify water uses and specify the water source for each

☐ Irrigation (e.g. river)

☐ Fertigation/hydroponics (e.g. rainwater)

☐ Agricultural chemical application (e.g. farm pond sourced from a river)

☐ Frost and heat protection (e.g. groundwater)

☐ Post-harvest cooling (e.g. town water)

☐ Produce washing (e.g. town water)

☐ Cleaning and sanitation (e.g. town water)

☐ Handwashing and amenities (e.g. town water)

☐ Other (specify): _____

3.1.3 Identify all potential sources of contamination in surface water source catchment areas

☐ Livestock grazing

☐ Wildlife activity

- ☐ Waterbird activity on dams or reservoirs
- ☐ Animal operations (e.g. dairy, feedlot, poultry or piggery)
- ☐ Composting facilities
- ☐ Septic system
- ☐ Storm run-off
- ☐ Flood-prone area
- ☐ Manure stockpiles
- ☐ Landfill or waste management operation
- ☐ Other agricultural activities (specify): _____

3.1.4 What measures are used to protect water sources from contamination?

- ☐ Area-wide assessment of water contamination sources and routes
- ☐ Fencing around dams, ponds or water storage to exclude livestock/wildlife and humans
- ☐ Dam or pond lined with plastic, concrete or other impermeable material
- ☐ Vegetated buffer zones around water sources
- ☐ Stormwater diversion away from water sources
- ☐ Water storage covers or enclosed tanks
- ☐ Water storage infrastructure is designed to minimise run-off entering the water source
- ☐ Sediment traps or settling ponds are installed
- ☐ Signage and restricted access to water sources
- ☐ Other (specify): _____

3.1.5 If irrigation water is sourced from a river, creek, stream, dam, spring or other surface water source, how is microbial water quality managed?

- ☐ Water is applied directly to crops without being treated
- ☐ Water is stored in an on-farm dam or reservoir before use
- ☐ Coarse water treatment before use (e.g. coarse filtration)
- ☐ Fine water treatment (e.g. micro- or ultra-filtration, reverse osmosis)
- ☐ Water is disinfected before use (e.g. chlorination, UV treatment)
- ☐ Modified irrigation practices (e.g. drip irrigation)
- ☐ Water source protection measures are implemented
- ☐ Alternative water sources are available if the water quality is unsuitable
- ☐ Harvest restrictions following poor water quality (*E. coli* > 100 cfu/100 mL)
- ☐ Withholding overhead irrigation for pathogen die-off before harvest (*E. coli* > 100 cfu/100 mL)
- ☐ Additional monitoring following rainfall or flooding
- ☐ Other (specify): _____

3.1.6 What is the irrigation water testing frequency?

- ☐ Annual
- ☐ Seasonal (e.g. summer, winter)
- ☐ Monthly
- ☐ Before each crop cycle
- ☐ Following significant rainfall or flooding
- ☐ No testing conducted
- ☐ No testing is required as only potable water is used

3.1.7 What microbiological parameters are included in your water testing program?

- ☐ *Escherichia coli* count
- ☐ Total coliforms count
- ☐ Faecal coliforms count
- ☐ Enterococci count
- ☐ *Salmonella* spp.
- ☐ *Listeria* spp.
- ☐ *Listeria monocytogenes*
- ☐ STEC
- ☐ *Campylobacter* spp.
- ☐ *Legionella* spp.
- ☐ Other (specify): _____

3.1.8 How are water quality records used?

- ☐ Water test reports are used once for auditing purposes
- ☐ Historical water quality trends are analysed
- ☐ Corrective actions are documented when limits are exceeded
- ☐ Other (specify): _____

3.1.9 Water quality verification

- ☐ Irrigation water that contacts the edible part of the crop is verified as meeting *E. coli* <100 cfu/100 mL
- ☐ Water quality results are reviewed before the water is used
- ☐ Corrective actions are implemented when water quality limits are exceeded
- ☐ Other (specify): _____

3.1.10 If water contacts the edible part of leafy vegetables within 48 hours of harvest, what type of water is used?

- ☐ Potable water
- ☐ Water treated to *E. coli* <1 cfu/100 mL
- ☐ Water treated to *E. coli* <100 cfu/100 mL
- ☐ Other (specify): _____

3.1.11 What actions are taken when water quality limits are exceeded (e.g. *E. coli* >100 cfu/100 mL)?

- ☐ Repeat water testing for target pathogens (e.g. STEC)
- ☐ Investigate the source of contamination
- ☐ Treat water before use
- ☐ Change irrigation method
- ☐ Suspend use of the affected water source
- ☐ Delay harvest
- ☐ Use an alternative water source
- ☐ Microbiological testing of produce
- ☐ Other (specify): _____

3.2 Seed and seedling management

- ☐ Purchased from commercial suppliers
- ☐ Produced on the farm
- ☐ Both are purchased and produced on the farm

3.2.1 How do you ensure that seeds and seedlings are suitable for leafy vegetable production

- ☐ Seeds and seedlings are sourced from approved suppliers
- ☐ Supplier details are recorded and retained
- ☐ Batch or lot numbers are recorded
- ☐ Traceability records are maintained
- ☐ Other (specify): _____

3.3 Agricultural chemicals

3.3.1 Which agricultural chemicals or inputs are used during production, harvesting and post-harvest handling?

- ☐ No agricultural chemicals used
- ☐ Insecticides
- ☐ Herbicides
- ☐ Fungicides
- ☐ Rodenticides
- ☐ Molluscicides
- ☐ Plant growth regulators
- ☐ Foliar nutrients
- ☐ Soil conditioners
- ☐ Biological control products
- ☐ Pesticides derived from natural sources
- ☐ Detergents, sanitisers and disinfectants
- ☐ Other (specify): _____

3.3.2 Chemical approval and verification

How do you ensure agricultural chemicals are suitable for use?

- ☐ Chemicals are stored and used according to label instructions
- ☐ Chemicals are registered for the intended use
- ☐ Safety data sheets (SDS) are available
- ☐ Chemical inventory is maintained
- ☐ Staff are trained in chemical handling and application
- ☐ Other (specify): _____

3.3.3 Chemical application records

Do you maintain a chemical application diary or equivalent records?

- ☐ Yes
- ☐ No

If yes, indicate what information is recorded.

- ☐ Produce name
- ☐ Active ingredient

- ☐ Batch number (where applicable)
- ☐ Crop, field or block treated
- ☐ Application date and time
- ☐ Application rate/dose
- ☐ Application method
- ☐ Weather conditions
- ☐ Name of applicator
- ☐ Withholding period
- ☐ Harvest date
- ☐ Other (specify): _____

3.3.4 Chemical storage and traceability

- ☐ Chemical purchase records are maintained
- ☐ Chemical inventory is maintained
- ☐ Chemical storage area is secured
- ☐ Chemical batch numbers are recorded
- ☐ Chemical usage is traceable to specific crops and fields
- ☐ Disposal records are maintained
- ☐ Other (specify): _____

3.3.5 Risk assessment

Have food safety risks associated with seeds, seedlings and agricultural chemicals been assessed and documented?

- ☐ Yes
- ☐ No

Describe any significant risks identified and the control measures implemented _____

3.4 Soil amendments, fertilisers and compost

3.4.1 Soil amendments, fertilisers and compost used on the farm

- ☐ Compost containing no animal products
- ☐ Compost containing animal manure
- ☐ Compost containing other animal byproducts, such as bonemeal
- ☐ Untreated/raw animal manure (e.g. poultry litter, cattle manure)
- ☐ Partially treated/aged animal manure (e.g. poultry litter, cattle manure)
- ☐ Mixture of compost and untreated/raw animal manure
- ☐ Mixture of compost and partially treated/aged animal manure
- ☐ Biofertilisers containing animal byproducts
- ☐ Biostimulants
- ☐ Compost tea
- ☐ Other (specify): _____

3.4.2 Traceability of soil amendments and fertilisers

Does the business maintain records for soil amendments, fertilisers, compost, manure and biological soil amendments?

☐ Yes

☐ No

If yes, which information is recorded?

☐ Produce name

☐ Supplier

☐ Batch or lot number

☐ Date received

☐ Quantity received

☐ Storage location

☐ Application date and rate

☐ Crop planted/sown

☐ Field/block where applied

☐ Person responsible for the application

☐ Other (specify): _____

3.4.3 On-farm production of compost and soil amendments

Does the business produce compost, soil amendments, fertilisers, compost teas or other biological soil amendments on-site?

☐ Yes

☐ No

If compost or biological soil amendments are produced on-site, how are microbiological risks managed?

☐ Risk assessment of feedstock

☐ Process is monitored and recorded (e.g. composting temperature, moisture, aeration/turning)

☐ Final product (e.g. compost) is tested for microbiological parameters

☐ Organic amendment is protected from recontamination during storage

☐ Organic amendment production records are maintained

☐ Other (specify): _____

3.4.4. Microbiological parameters for compost and biological soil amendments

☐ *Salmonella* spp.

☐ *E. coli* count

☐ Total and faecal coliform counts

☐ Compost is tested for other pathogens (e.g. *Listeria monocytogenes* and STEC)

Compost is tested according to the Australian standard AS4454–2012 by a NATA-accredited laboratory

☐ Certificates of analysis are retained

☐ No microbiological testing is conducted

☐ Other (specify): _____

3.4.4 Application of soil organic amendments

Timing of application

- ☐ Applied before sowing/planting only
- ☐ Applied after planting but before canopy development
- ☐ Applied after canopy development as side dressing or top dressing
- ☐ Applied close to harvest
- ☐ Other (specify): _____

3.4.5 Contact with edible portions of the crop

Do any biological fertilisers, compost teas, biostimulants or animal-derived products come into direct contact with the edible part of leafy vegetables?

- ☐ Yes
- ☐ No

If yes, describe the controls implemented to minimise food safety risks _____

3.4.6 Risk management of organic soil amendments containing animal-derived materials

If organic soil amendments containing animal-derived materials (e.g. composted manure, poultry litter, animal-based fertilisers, compost teas or other biological soil amendments) are used, how are potential food safety risks managed?

- ☐ Only fully composted and treated organic amendments are used
- ☐ Organic amendments are sourced from approved suppliers
- ☐ Certificates of analysis or supplier declarations are obtained and retained
- ☐ Composting processes are validated, verified and documented
- ☐ Organic amendments are microbiologically tested before application
- ☐ Organic amendments are incorporated into the soil before planting
- ☐ Organic amendments are not applied directly to the edible part of the crop
- ☐ Soil samples are tested after the organic amendments are applied
- ☐ Application to harvest intervals are implemented and documented
- ☐ Produce is tested for biological hazards before harvest
- ☐ Other (specify): _____

3.4.7 Risk management of organic amendment storage

If compost, manure, compost feedstocks, or other biological soil amendments are stored on-site, how are potential food safety risks managed?

- ☐ Organic amendments are stored in a designated area
- ☐ Storage areas are located away from production fields and processing sites
- ☐ Storage areas are located away from irrigation water sources, dams, creeks, rivers, streams, bores and drainage channels
- ☐ Storage areas are positioned to minimise contamination risks to crops and water sources
- ☐ Composting and manure storage areas are identified on a farm map
- ☐ Storage areas are located outside flood-prone areas
- ☐ Bunds, retaining walls or containment structures are used to prevent run-off

- ☐ Impermeable pads, concrete surfaces or liners are used beneath storage areas
- ☐ Storage areas are regularly inspected following rainfall
- ☐ Windbreaks or vegetation buffers are installed between storage areas and production fields
- ☐ Prevailing wind direction has been considered when selecting storage locations
- ☐ Storage areas are regularly inspected for animal activity
- ☐ Raw materials are separated from treated or finished compost
- ☐ Compost batches are clearly identified
- ☐ Other (specify): _____

Section 4. Growing site

4.1. Have you identified any risks associated with your growing site?

- ☐ Livestock access to production fields
- ☐ Livestock operations (e.g. cattle, sheep, poultry) near the growing site
- ☐ Wildlife intrusion (e.g. kangaroos, birds, feral animals)
- ☐ Extreme weather (e.g. flooding)
- ☐ Run-off or aerosol from neighbouring animal operations
- ☐ Chemical contamination
- ☐ Spray drift from neighbouring farm operations
- ☐ Heavy vehicle use (frequent truck traffic creating dust)
- ☐ Wastewater or septic tanks near the growing site
- ☐ Toxic weeds (e.g. *Datura*) near the growing site
- ☐ Other (specify): _____

4.2. Mitigation measures to protect the crops from potential contamination

- ☐ Buffer zones (separation distance)
- ☐ Windbreaks
- ☐ Physical barriers (e.g. fencing)
- ☐ Netting
- ☐ Ditches
- ☐ Raised mounds
- ☐ Drainage channels
- ☐ Other (specify): _____

4.3. Does your site have any known natural contaminants (e.g. cadmium) or any persistent agricultural and veterinary chemicals above maximum residue limits (MRLs)? If yes, how do you manage this?

4.4. Are records of land history, hazard analysis, pre-plant field inspections and tests, such as soil tests, kept?

4.5 Extreme weather hazards

- ☐ Flooding (river, creek, stormwater, flash flooding)
- ☐ Cyclones/tropical storms
- ☐ Severe windstorms
- ☐ Dust storms
- ☐ Bushfires
- ☐ Heavy rainfall (>10 mm per hour)
- ☐ Hailstorms
- ☐ Drought
- ☐ Heatwaves
- ☐ Frost
- ☐ Other: _____

4.5.1 Site vulnerability assessment

- ☐ Production areas are located in flood-prone areas
- ☐ Production areas are exposed to strong wind
- ☐ Production areas are susceptible to dust contamination
- ☐ Production areas are located near bushfire-prone vegetation
- ☐ Drainage is poor in production areas
- ☐ Reliance on a single water source during drought conditions
- ☐ Packing or storage facilities susceptible to storm damage
- ☐ Risk of contamination from neighbouring properties during extreme weather
- ☐ No significant vulnerabilities identified
- ☐ Other: _____

4.5.2 Risk management measures

- ☐ Windbreaks or shelterbelts are established
- ☐ Inter-row vegetation or cover crops are used to minimise dust
- ☐ Drainage channels are maintained and functional
- ☐ Flood mitigation measures are in place
- ☐ Regular weather monitoring is undertaken
- ☐ Emergency response procedures are documented
- ☐ Produce is inspected after extreme weather
- ☐ Contaminated produce is identified and segregated
- ☐ Contaminated produce is disposed of appropriately
- ☐ Flood-affected land is rested before replanting
- ☐ Bushfire and smoke contamination are assessed before harvest
- ☐ Water quality is assessed after flooding or contamination
- ☐ Staff are trained in extreme weather response procedures
- ☐ Records are maintained for corrective actions in response to extreme weather
- ☐ Other: _____

4.5.3 Remedial actions after extreme weather

- ☐ Harvest is suspended until risks are assessed
- ☐ Growing areas are inspected for contamination or damage
- ☐ Produce is inspected before harvest or sale
- ☐ Water sources are inspected and tested if required
- ☐ Infrastructure is inspected and repaired where necessary
- ☐ Corrective actions are documented
- ☐ Event recorded in the extreme weather register
- ☐ Other: _____

Section 5. Premises and equipment

5.1 Premises

5.1.1 Have you assessed your packing shed, storage facilities and surrounding premises for potential contamination risks?

- ☐ Yes
- ☐ No

5.1.2 Identify potential sources of contamination that might affect produce, packaging materials or produce handling areas

- ☐ Dust from farm roads
- ☐ Dust from neighbouring properties
- ☐ Windblown soil and debris
- ☐ Unsealed roadways or access tracks
- ☐ Soil and mud carried by vehicles, machinery and employee footwear
- ☐ Heavy farm machinery operating near the packing shed
- ☐ Dirty harvest machinery entering packing areas
- ☐ Forklift traffic carrying dirt into clean areas
- ☐ Fuel, oil or grease contamination from machinery
- ☐ Machinery storage adjacent to packing operations
- ☐ Other: _____

Premises and infrastructure risks

- ☐ Poor drainage around buildings
- ☐ Damaged floors, walls or structures
- ☐ Inadequate separation between clean and dirty operations
- ☐ Inadequate waste disposal facilities
- ☐ Inadequate lighting for cleaning and inspection activities
- ☐ Other: _____

Pest and animal risks

- ☐ Birds entering the packing shed
- ☐ Rodents in storage or packing areas
- ☐ Insects in produce handling areas
- ☐ Wildlife entering premises

- ☐ Domestic animals, including pets, accessing produce areas
- ☐ Pest harbourage around buildings
- ☐ Other: _____

Chemical contamination risks

- ☐ Agricultural chemicals and fertilisers are stored near produce handling areas
- ☐ Chemical preparation areas are next to produce operations
- ☐ Chemical spills or leaks
- ☐ Cleaning chemicals are stored incorrectly
- ☐ Other: _____

5.1.3 Risk management measures implemented

- ☐ Packing shed is located away from major contamination sources
- ☐ Produce handling areas are separated from machinery storage areas
- ☐ Produce handling areas are separated from chemical storage areas
- ☐ Premises are designed to allow effective cleaning and sanitising
- ☐ Adequate drainage is installed around buildings
- ☐ Waste storage is located away from produce handling areas
- ☐ Access to packing and storage areas is restricted
- ☐ Designated machinery cleaning area is established
- ☐ Concrete wash-down pad is provided for machinery cleaning
- ☐ Machinery is cleaned before entering the packing shed areas
- ☐ Vehicle traffic routes are clearly designated
- ☐ Dirty and clean traffic flows are separated
- ☐ Forklifts and vehicles are routinely cleaned and inspected
- ☐ Roadways are maintained and speed limits are enforced to minimise dust
- ☐ Packing shed doors are kept closed when practical
- ☐ Produce is protected from dust contamination
- ☐ Floors and work areas are regularly cleaned
- ☐ Pest control program is implemented
- ☐ Domestic animals are excluded from the premises
- ☐ Chemicals are stored in designated storage areas
- ☐ Fuel and lubricants are stored separately from produce areas
- ☐ Spill response procedures are implemented
- ☐ Chemical handling areas are clearly identified

5.1.4 Monitoring and verification

- ☐ Premises are inspected routinely for contamination risks
- ☐ Machinery cleanliness is checked before it enters the packing areas
- ☐ Drainage systems are inspected and maintained
- ☐ Pest activity is monitored and recorded
- ☐ Waste areas are inspected routinely
- ☐ Corrective actions are documented when issues are identified

5.2 Equipment

5.2.1 Have you assessed harvest and post-harvest equipment for potential contamination risks?

- ☐ Yes
- ☐ No

Identify the harvest equipment used on the farm

- ☐ Harvest knives
- ☐ Hand-held harvest tools
- ☐ Harvest bins and crates
- ☐ Bulk produce bins
- ☐ Harvest trailers
- ☐ Tractors used during harvest
- ☐ Forklifts used during harvest
- ☐ Mechanical harvesters
- ☐ Field packing equipment
- ☐ Other: _____

Harvest equipment cleaning and sanitising controls

- ☐ Soil and debris are removed before and after use
- ☐ Equipment is visually inspected before use
- ☐ Equipment is cleaned at the end of each harvest day
- ☐ Equipment is washed using water and detergent
- ☐ Equipment is sanitised using an approved sanitiser
- ☐ Harvest bins or crates are inspected before use
- ☐ Harvest tools are stored in a clean, designated area
- ☐ Cleaning records are maintained
- ☐ Other: _____

Identify post-harvest equipment used on the farm

- ☐ Produce bins
- ☐ Packing tables
- ☐ Conveyors
- ☐ Rollers
- ☐ Sorting equipment
- ☐ Grading equipment
- ☐ Washing equipment
- ☐ Spinning/drying equipment
- ☐ Packing machinery
- ☐ Pallet jacks
- ☐ Forklifts
- ☐ Cooling and cold room equipment
- ☐ Storage racks
- ☐ Transport vehicles

☐ Water treatment equipment

☐ Other: _____

Post-harvest equipment cleaning and sanitising controls

☐ Equipment is cleaned before and after use

☐ Equipment is washed with clean water and approved detergent

☐ Equipment is sanitised using approved sanitiser

☐ Food contact surfaces are inspected before operation

☐ Cleaning tools are maintained in a hygienic condition

☐ Cleaning schedules are displayed in work areas

☐ Cleaning records are maintained

☐ Other: _____

Transport vehicles and produce handling equipment

☐ Trucks are inspected before loading

☐ Vehicle floors are cleaned before loading produce

☐ Vehicles are free from chemicals, fuel and waste materials

☐ Produce is protected from dust and weather during transport

☐ Vehicle cleanliness records are maintained

☐ Pallets are inspected before use

☐ Forklifts are inspected and cleaned routinely

☐ Other: _____

5.2.2 Monitoring and verification

☐ Pre-operational inspections are conducted

☐ Cleaning effectiveness is visually verified

☐ Sanitising procedures are verified

☐ Equipment maintenance inspections are completed

☐ Staff are trained in cleaning and sanitising procedures

☐ Cleaning records are reviewed routinely

☐ Corrective actions are documented when deficiencies are identified

5.2.3 How do you keep equipment, premises and vehicles used for leafy vegetables clean and sanitary?

☐ Clean to remove visible matter

☐ Rinse with water after cleaning

☐ Rinse with water including a detergent

☐ Rinse with water including a detergent and then sanitise with a sanitiser

☐ Other: _____

5.2.4 How often do you clean and sanitise your harvest equipment?

☐ Before/after each use

☐ Once a week

☐ Once a month

☐ Once a season

☐ Other: _____

5.2.5 Do you have an environmental monitoring plan (EMP) for the packing shed hygiene?

- ☐ Yes
☐ No

5.2.6 How often do you swab produce contact surfaces to detect environmental pathogens?

- ☐ Daily
☐ Weekly
☐ Monthly
☐ Once a season
☐ Never

5.2.7 How often do you swab non-contact surfaces to detect environmental pathogens?

- ☐ Daily
☐ Weekly
☐ Monthly
☐ Once a season
☐ Never

5.2.8 What are the target pathogens or indicator organisms used for your EMP?

- ☐ *Listeria* spp.
☐ *Listeria monocytogenes*
☐ *Salmonella* spp.
☐ Other(s) : _____

5.2.9 How do you keep equipment, premises and vehicles used to process leafy vegetables clean and sanitary?

- ☐ Clean to remove visible matter
☐ Rinse with water after cleaning
☐ Rinse with water including a detergent
☐ Rinse with water including a detergent and then sanitise with a sanitiser
☐ Other: _____

5.2.10 How often do you clean and sanitise your processing equipment?

- ☐ Before/after each use
☐ Once a week
☐ Once a month
☐ Once a season
☐ Other: _____

Section 6. Temperature management

6.1. How do you maintain harvested produce at temperatures that minimise bacterial growth and preserve produce quality?

- ☐ Leafy vegetables are harvested during the cooler parts of the day (e.g. early morning)
- ☐ Harvested produce is kept out of direct sunlight during harvest (e.g. under shade cloth, in covered bins or in shaded areas)
- ☐ Leafy vegetables are left in the field after harvest until collection for processing
- ☐ Leafy vegetables are harvested and transferred to temperature-controlled storage before collection for processing
- ☐ Leafy vegetables are harvested and stored in a shed at ambient temperature before collection for processing. Vegetables are collected on the same day they are harvested.
- ☐ Harvested produce is stored under temperature-controlled conditions ($\leq 5^{\circ}\text{C}$) before transport from the farm to the processor/markets
- ☐ Storage temperatures are monitored and recorded

6.2 How are harvested leafy vegetables pre-cooled before storage, processing or transport?

- ☐ Air cooling (standard cool room refrigeration)
- ☐ Forced-air cooling
- ☐ Vacuum cooling
- ☐ Hydro-cooling (using potable water)
- ☐ No pre-cooling applied
- ☐ Other: _____

6.3 What is the quality of the water that comes into direct contact with leafy vegetables after harvest (e.g. hydro-cooling, hydro-vac cooling, rinsing, washing)?

- ☐ Potable water (drinking water quality, *E. coli* < 1 cfu/100 mL)
- ☐ Treated water that has been tested, meeting potable standards (*E. coli* < 1 cfu/100 mL)
- ☐ Untreated surface water (e.g. dam, river, creek)
- ☐ Untreated groundwater (e.g. bore water)
- ☐ Water quality unknown
- ☐ Not applicable: water does not come into direct contact with leafy vegetables after harvest
- ☐ Other (please specify): _____

Section 7. Washing and sanitising of leafy vegetables

7.1 What washing equipment or washing methods are used for leafy vegetables?

- ☐ No washing undertaken
- ☐ Single wash tank/flume
- ☐ Multi-stage wash tanks/flumes (e.g. double or triple wash systems)
- ☐ Conveyor-based spray washing system with overhead and/or side nozzle sprayers
- ☐ Immersion/submersion wash tank for herbs, spring onions or similar products
- ☐ Bubble washer/agitation wash system

- ☐ Manual washing in tanks or tubs
- ☐ Hand-held hose or spray washing
- ☐ Field washing/rinsing during harvest (e.g. lettuce heads)
- ☐ Other field-based washing (please specify): _____

7.2 What is the quality of water used for washing and rinsing leafy vegetables?

- ☐ Potable water (drinking water quality)
- ☐ Treated water that has been tested to meet potable water standards
- ☐ Untreated bore water
- ☐ Untreated surface water (e.g. dam, river, creek)
- ☐ Other (please specify): _____

7.3 How is wash water sanitised?

- ☐ No sanitiser used
- ☐ Chlorine (sodium hypochlorite)
- ☐ Calcium hypochlorite
- ☐ Chlorine dioxide
- ☐ Peracetic acid (PAA)
- ☐ Ozone
- ☐ Other (please specify): _____

7.4 How is sanitiser added to wash water? (tick one)

- ☐ Automated dosing system
- ☐ Manual dosing
- ☐ Combination of automated and manual dosing
- ☐ No sanitiser used

7.5 How is sanitiser concentration monitored?

- ☐ Continuous automated monitoring
- ☐ Test strips
- ☐ Hand-held digital meter
- ☐ Not monitored
- ☐ Other (please specify): _____

7.6 How often is sanitiser concentration checked and recorded? (tick one)

- ☐ Continuously (e.g. every 15 min)
- ☐ Every hour
- ☐ Every 2–4 hours
- ☐ Once per shift (e.g. every 8 hours)
- ☐ Daily
- ☐ Not recorded
- ☐ Other (please specify): _____

7.7 What process controls are used during washing?

- ☐ Sanitiser concentration is monitored and adjusted
- ☐ Wash water pH is monitored

- ☐ Wash water oxidation-reduction potential (ORP) is monitored
- ☐ Wash water temperature is monitored
- ☐ Chemical oxygen demand (COD) is monitored
- ☐ Water turbidity is monitored
- ☐ Water change criteria documented
- ☐ Records maintained
- ☐ Other (please specify): _____

7.8 How often is wash water replaced? (tick one)

- ☐ Continuously replenished with overflow
- ☐ At defined intervals during production
- ☐ At the end of each production batch
- ☐ At the end of each shift
- ☐ Daily
- ☐ Only when visibly dirty
- ☐ Other (please specify): _____

7.9 What criteria are used to decide when wash water is changed?

- ☐ At defined intervals during processing (e.g. every 4 hours)
- ☐ Sanitiser concentration falls below the target level
- ☐ Excess organic matter is present
- ☐ Water turbidity exceeds the set limit
- ☐ End of production batch
- ☐ End of production shift
- ☐ Visual assessment only
- ☐ Other (please specify): _____

7.10 What is the approximate water-to-produce ratio used during washing? (tick one)

- ☐ Less than 5:1
- ☐ 5:1 to 10:1
- ☐ Greater than 10:1
- ☐ Not measured
- ☐ Other (please specify): _____

7.11 How is wash water volume managed relative to produce throughput?

- ☐ Water-to-produce ratio is documented and monitored
- ☐ Fresh water is continuously added during washing
- ☐ Water overflow is maintained to remove organic matter
- ☐ Water quality parameters (e.g. sanitiser concentration, turbidity) are used to determine water replacement frequency
- ☐ Water-to-produce ratio is not monitored
- ☐ Other (please specify): _____

7.12 What temperature controls are applied to wash water?

- ☐ Wash water temperature is monitored
- ☐ Wash water temperature is maintained within a defined range
- ☐ Wash water is cooled before use
- ☐ No temperature controls are applied
- ☐ Other (please specify): _____

7.13 Are documented critical limits or target operating ranges established for washing operations? Please specify each limit/range.

- ☐ Sanitiser concentration (e.g. free chlorine minimum 10 ppm and maximum 25 ppm)
- ☐ pH (e.g. 6.5 to 7.5)
- ☐ Water temperature
- ☐ Turbidity
- ☐ Contact time (e.g. 30 seconds to 2 minutes)
- ☐ Water-to-produce ratio
- ☐ No documented limits are established
- ☐ Other (please specify): _____

Section 8. Skills and knowledge

8.1. How do you train farm workers, harvesters, produce handlers and processing staff in food safety?

- ☐ An external provider is engaged to develop or deliver food safety training
- ☐ New staff are trained on-site by experienced personnel
- ☐ New staff receive food safety induction training before starting work
- ☐ Staff receive documented training on standard operating procedures (SOPs)
- ☐ Staff undertake online food safety training courses
- ☐ Supervisors provide ongoing coaching and monitoring
- ☐ Refresher training is provided following incidents, complaints or corrective actions
- ☐ Food safety training records are maintained
- ☐ I do not employ staff
- ☐ Other (please specify): _____

8.2. How do you ensure food safety information is understood by workers from culturally and linguistically diverse (CALD) backgrounds?

- ☐ Training is provided in the worker's preferred language
- ☐ Training materials are translated into relevant languages
- ☐ Interpreters are used during training sessions
- ☐ Bilingual supervisors or team leaders help with training
- ☐ Visual work instructions (e.g. photographs, diagrams, pictograms) are used
- ☐ Demonstrations and practical training are provided
- ☐ Training materials use simple language and appropriate text
- ☐ Food safety signs and posters are displayed in multiple languages
- ☐ Supervisors routinely verify workers' understanding of food safety requirements

- ☐ Training effectiveness is assessed and documented
- ☐ Other (please specify): _____

8.3. How do you verify that workers understand food safety requirements?

- ☐ Observation of work practices
- ☐ Verbal questioning
- ☐ Practical competency assessment
- ☐ Refresher training where gaps are identified
- ☐ Written assessment or quiz
- ☐ Other (please specify): _____

8.4. How often do staff receive food safety training?

- ☐ When starting employment
- ☐ Before the start of each harvest season
- ☐ Annual refresher training
- ☐ Following changes to equipment, processes or procedures
- ☐ Following food safety incidents or customer complaints
- ☐ Periodic toolbox meetings or refresher sessions
- ☐ No refresher training is provided
- ☐ Other (please specify): _____

8.5. What food safety topics are included in staff training?

- ☐ Personal hygiene and handwashing
- ☐ Illness reporting requirements
- ☐ Harvest hygiene practices
- ☐ Cleaning and sanitising procedures
- ☐ Good documentation practices
- ☐ Water quality management
- ☐ Chemical handling and storage
- ☐ Foreign matter prevention
- ☐ Glass and brittle plastic
- ☐ Temperature management and cold chain controls
- ☐ Allergen awareness
- ☐ Produce traceability and recall procedures
- ☐ Identification and management of unacceptable produce
- ☐ Environmental monitoring practices
- ☐ Pest control
- ☐ Food defence (e.g. sabotage)
- ☐ Other (please specify): _____

8.6. Are harvest crews, field workers and supervisors trained to identify and report field conditions that might pose a food safety risk to leafy vegetables?

- ☐ Signs of animal activity (e.g. grazing, tracks, burrows, nesting, feathers)
- ☐ Animal faeces in production areas
- ☐ Evidence of domestic livestock intrusion

- ☐ Evidence of wildlife intrusion
- ☐ Presence of toxic weeds or poisonous plants
- ☐ Flooding of production areas
- ☐ Run-off from adjacent land
- ☐ Ponding or standing water in fields
- ☐ Excessive dust
- ☐ Severe weather damage (e.g. from hail, wind or storm)
- ☐ Chemical spray drift from neighbouring properties
- ☐ Foreign objects in production areas
- ☐ Signs of produce contamination during harvest
- ☐ Staff are trained to stop harvesting and notify a supervisor when a food safety hazard is identified
- ☐ Staff are trained to establish and identify no-harvest buffer zones around contaminated areas
- ☐ Supervisors are trained to assess, document and manage identified food safety hazards
- ☐ Training records are maintained
- ☐ Other (please specify): _____

8.7. What actions are workers instructed to take when a potential food safety hazard is identified in the field?

- ☐ Immediately report the hazard to a supervisor
- ☐ Stop harvesting in the affected area
- ☐ Segregate potentially affected produce
- ☐ Establish a no-harvest or exclusion zone
- ☐ Record the incident
- ☐ Await supervisor approval before starting harvest
- ☐ Other (please specify): _____

Section 9. Health and hygiene of staff and visitors

9.1. What health and hygiene controls are implemented on your farm or packing facility?

- ☐ Documented health and hygiene policy for staff and visitors
- ☐ Documented handwashing procedures
- ☐ Documented illness reporting procedures
- ☐ Staff illness register maintained
- ☐ Visitor sign-in procedures
- ☐ Visitor hygiene requirements
- ☐ Toilets are available for staff and visitors
- ☐ Handwashing facilities are available in production areas
- ☐ Toilet and handwashing facilities are available in harvesting areas
- ☐ Portable field sanitation facilities are available where required
- ☐ Personal protective clothing is provided where appropriate

- ☐ Contractors are required to comply with site hygiene requirements
- ☐ Other (please specify): _____

9.2. What health conditions must be reported before handling produce?

- ☐ Vomiting, diarrhoea and fever associated with illness
- ☐ Open wounds, cuts or infected skin lesions
- ☐ Communicable diseases
- ☐ Other (please specify): _____

9.3. How do you ensure staff comply with hygiene requirements?

- ☐ Supervisor monitoring
- ☐ Routine workplace inspections
- ☐ Site induction training
- ☐ Refresher training
- ☐ Handwashing signage
- ☐ Corrective action for non-compliance
- ☐ Internal audits
- ☐ Other (please specify): _____

9.4. Provide a site map showing the location of toilets, handwashing stations and hygiene facilities.

- ☐ Attached

Section 10. Sale or supply of unacceptable produce

10.1. How do you identify an unacceptable produce?

- ☐ Visual inspection during harvest/packing
- ☐ Quality assurance inspections
- ☐ Customer specifications
- ☐ Weather damage assessments
- ☐ Foreign matter inspections
- ☐ Pest or animal contamination inspections
- ☐ Microbiological testing results
- ☐ Other (please specify): _____

10.2. How is an unacceptable produce managed?

- ☐ Clearly identified and segregated
- ☐ Held in a designated rejection area
- ☐ Recorded in rejection records
- ☐ Investigated before disposal
- ☐ Disposed of off-site
- ☐ Composted on-site
- ☐ Sent for stockfeed where permitted
- ☐ Sent for further processing where legally permitted
- ☐ Other (please specify): _____

10.3. How do you manage weather-damaged produce to prevent contamination of unaffected produce?

- ☐ Damaged produce is identified and separated during harvest
- ☐ Damaged produce is kept separate throughout packing and storage
- ☐ Damaged produce is clearly identified and labelled
- ☐ Damaged produce is disposed of appropriately
- ☐ Additional inspections are conducted following adverse weather
- ☐ Harvest of affected blocks is delayed pending assessment
- ☐ Other (please specify): _____

10.4. Is there a documented procedure for managing rejected, recalled or non-conforming products?

- ☐ Yes
- ☐ No

Appendix 3

Shiga toxin-producing *Escherichia coli* contamination of leafy vegetables and risk management

Shiga toxin-producing *Escherichia coli* (STEC) are a sub-group of *Escherichia coli* (*E. coli*) bacteria that produce Shiga toxins, which can cause severe foodborne illness in humans. STEC infections can cause a wide range of symptoms, from mild gastroenteritis to severe conditions such as haemolytic uremic syndrome and life-threatening kidney disease. The severity of illness depends on factors such as the strain of STEC involved, the number of bacteria ingested, and the individual's health. Vulnerable populations, such as children, the elderly, and immunocompromised individuals, are at higher risk of severe disease outcomes.

STEC are transferred to humans via contaminated food and water, direct animal contact, environmental contamination and human-to-human transfer via the faecal–oral route. The most common foodborne sources of STEC include undercooked meat, unpasteurised milk, ready-to-eat meat products, seed sprouts and leafy vegetables.

STEC infections are caused by strains of *E. coli* that produce Shiga toxin (Stx). There are 2 main types (Stx1 and Stx2), and the Stx toxin genes (Stx1 and Stx2) are carried by lambdoid bacteriophages integrated into the *E. coli* chromosome. Additional virulence genes are consistently associated with severe illness, most notably the *eae* gene, which encodes the intimin protein required for adherence. However, this virulence factor is not always essential for illness severity (European Food Safety Authority, EFSA 2020). The severity of illness caused by STEC depends on the combination of Stx genes and additional virulence factors.

STEC serogroups

Among about 470 serogroups of STEC, the most commonly associated with serious human illness is O157. Other strains are grouped as non-O157. In Australia, the O157 has been reported to be the main STEC serogroup contributing to more than half of all STEC isolates serotyped, followed by O111 and O26 (Vally et al. 2012; Ingle et al. 2019). Several other serogroups have been reported with low prevalence.

In the USA, there are 6 main non-O157 strains, including O26, O45, O103, O111, O121 and O145 (USDA 2012), while in Europe, there are 5 leading non-O157 strains, including O26, O103, O91, O146 and O145 (EFSA 2020).

In Europe, all STEC strains are considered pathogenic in humans, capable of causing at least diarrhoea and, based on the analysis of the Stx sub-types and the presence/absence of the *eae* gene, all STEC sub-types can be associated with severe illness (EFSA 2020).

STEC illness notifications

STEC infection is a notifiable disease in Australia. Between 2000 and 2010, there were 822 notifications of STEC illness in Australia, making the annual rate 0.4 cases per 100,000 per year (Vally et al. 2012). From 2011 to 2024, there were 6,677 STEC notifications, increasing the annual rate of cases significantly (1.99 cases per 100,000 per year; National Notifiable Diseases Surveillance System (NNDSS) 2025).

Although most cases of STEC infection in Australia are considered sporadic, major STEC outbreaks can occur, with the largest reported outbreak of serogroup O157 STEC in Australia occurring among 57 patients in Queensland in 2013, associated with exposure to an animal nursery at an agricultural show (Vasant et al. 2017). Further information on foodborne transmission of STEC in Australia is limited.

STEC sources

STEC are frequently isolated from the gastrointestinal tracts of various animal species including cattle, sheep, goats, pigs, horses, deer, rodents and birds (Persad and LeJeune 2014). Animals are exposed to STEC by direct or indirect contact with the faeces of a shedding animal. Most animals lack receptors for Shiga toxin, and their presence does not typically lead to disease. In humans, the presence of additional virulence factors alongside the Stx gene is linked to disease development (Persad and LeJeune 2014).

Healthy cattle are regarded as the primary reservoir of STEC. In an Australian study on beef cattle faeces, the prevalence of *E. coli* O157 was highest (6.7%), followed by 1.0% for O26 and 0.3% for O111. No STEC strains of the O45, O103, O121, or O145 serotypes were isolated (Mellor et al. 2016). The study also reported a higher prevalence of STEC among younger animals than adult animals. **Sheep** are also a reservoir for STEC in Australia, with the serotype of importance being O26. However, the risk of human infection is low due to lower prevalence rates (Gyles 2007; Duffy et al. 2010). **Wild birds and animals** pose a unique risk because they can travel long distances, increasing the dissemination of STEC in the environment.

Major sources and routes of STEC contamination

The major sources and routes of STEC contamination in leafy vegetables are:

1. **Irrigation water:** one of the primary sources of STEC contamination is using contaminated water for irrigation. Water contaminated with faecal matter from animals (livestock and wildlife) can carry pathogens such as STEC, which then contaminate the surface of leafy vegetables. Surface water sources such as rivers, creeks and canals are highly prone to contamination with STEC from animal operations. Applying surface irrigation water with high levels of *E. coli* via an overhead irrigation system (Figure 66), particularly close to harvest, can elevate the risk of STEC contamination. Though *E. coli* could die off at the rate of 0.5 log per day, the residual population becomes the contaminant.
2. **Organic soil amendments:** raw or improperly composted manure contaminated with STEC can transfer these pathogens to leafy vegetables when used as fertilisers (Ongeng et al. 2015). STEC can be transferred to the leaves during production by direct contact with soil or indirect splashing with rain and overhead irrigation.
3. **Growing site:** the co-existence of fresh produce and livestock industries poses elevated risks of pathogen transfer from animal operations to the production field via contaminated irrigation water, dust storms and run-off. Compost yards and piles can be a significant risk for contaminating leafy vegetables in the field. They should be located as far away as possible and be screened or protected to avoid contamination via wind and run-off. Wildlife incursions in the production field and water sources are another major risk factor.
4. **Harvesting:** if workers or harvesting equipment contact contaminated water, soil, or surfaces, they can spread the bacteria onto the leafy vegetables. Inadequate personal and equipment hygiene can also contribute to cross-contamination.
5. **Cool chain management:** pre-cooling leafy vegetables immediately after harvest reduces microbial risk. Maintaining a cool chain is critical to minimise microbial proliferation, particularly for businesses transporting produce long distances between harvest and post-harvest processing.
6. **Post-harvest processing:** after harvest, leafy vegetables are washed in water to remove dirt and residues, but this water can be contaminated if sanitisers are not maintained at appropriate concentrations to compensate for organic and microbial loads on harvested produce (Figure 67).
7. **Extreme weather conditions:** heavy rainfall that results in run-off or flooding (Figure 68), dust storms, bushfires and heatwaves affect fresh produce safety (Singh 2023b). Natural disasters often exacerbate the transfer of microbial pathogens from the environment into production fields, water sources and post-harvest processing facilities.



Figure 66. Applying contaminated surface irrigation water with an overhead irrigation system increases the risk of leafy vegetable contamination.



Figure 67. The wash water must have appropriate sanitiser concentrations.



Figure 68. Extreme weather conditions, such as heavy rainfall, can transfer microbial pathogens from the environment into production fields, water sources and post-harvest processing facilities.

STEC risk management strategies

Global Food Safety Initiative (GFSI) benchmarked quality assurance schemes provide guidance for microbial risk management. Having these schemes in place can help with managing microbial risk, including STEC. Comprehensive food safety strategies must be implemented at various points along the leafy vegetable production and supply chain (Singh 2025). Essential risk management practices include:

Pre-harvest water quality management: irrigation water from surface sources such as rivers and canals should be pumped and stored in a dam or pond to allow the suspended solids to settle. Having sediment in irrigation water indicates a higher risk of faecal contamination. Using coarse filtration and frequent backflushing minimises the sediment and reduces the microbial population in irrigation water (Figure 69).

Irrigation water quality should be monitored regularly (Figure 70), at least once a month. Surface water quality deteriorates in summer and in response to extreme weather conditions such as heavy rainfall.

Generic *E. coli* is a reliable indicator of water quality, and higher levels of *E. coli* are linked to the presence of STEC and other pathogens in water.

The *E. coli* population in irrigation water for leafy vegetables should be no more than 100 cfu/100 mL (ANZG 2023). If overhead sprinklers are used to irrigate leafy vegetables, especially within 2 days of harvest, the water quality should be monitored closely, aiming for the lowest possible levels of *E. coli*.



Figure 69. Using coarse filtration and frequent backflushing minimises sediment and reduces the microbial population in irrigation water.



Figure 70. Collecting samples to test irrigation water.

Organic soil amendments: compost containing animal manure should be free from harmful pathogens (Figure 71). Commercial products must be treated in accordance with the [Australian Standard AS4454–2012 Compost, soil conditioner and mulch](#). Traceability of compost containing animal products (e.g. source, batch, certification) sourced and applied in the production system is important so corrective actions can be taken if required.

Co-existence with animal operations: animal operations located near land used for growing leafy vegetables are recognised as a significant risk for the transmission of STEC. Appropriate buffer zones between animals and leafy vegetable operations are required, along with transmission barriers such as perennial windbreaks. Extreme weather conditions (e.g. dust storms, heavy rainfall, cyclones) increase the transmission and spread of contamination from surrounding livestock operations. Proper drainage systems should be installed to curtail run-off risk from neighbouring animal operations.

Harvest and post-harvest

- Harvest equipment hygiene is crucial for managing cross-contamination risks.
- Rapid pre-cooling and maintaining a cool chain (<5 °C) are critical to suppress the growth and proliferation of bacterial pathogens such as STEC.
- Drinking quality water (<1 cfu/100 mL of *E. coli*) should be used for post-harvest cooling, washing, and sanitising leafy vegetables.
- Pre-wash rinsing the produce helps minimise organic load in wash tanks and remove the exudate from cut leaves. The triple washing process used for baby leaf processing should have an appropriate sanitiser concentration in each washing and sanitising tank (Figure 72).
- In response to extreme weather conditions (e.g. heavy rainfall or dust storms), additional measures such as pre-wash, high-pressure rinsing of leafy vegetables, frequent wash water changes, and increasing sanitiser concentrations and washing time should be undertaken.

Traceability: establishing traceability systems allows producers and retailers to track the produce's origin and quickly identify contamination sources when an outbreak or produce recall happens. Properly documenting each stage of the supply chain is essential for efficient trace-back procedures. Producers should maintain records of all farm inputs such as soil amendments, fertilisers and water used for leafy vegetable production and processing.



Figure 71. Microbiological sampling of compost samples.



Figure 72. Appropriate sanitiser concentrations should be in each washing and sanitising tank.

Safe Leafy Veg



Best practice guidance

