

Final report

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Identifying and managing the sources and routes of microbial contamination in leafy vegetables

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Public summary

This project (VG22002 – Identifying and managing the sources and routes of microbial contamination in leafy vegetables) strengthened food safety systems within the Australian leafy vegetable (LV) industry by identifying and managing microbial risks across production, harvest, and postharvest stages. The project supported growers and processors in developing risk-based preventive measures to manage microbial hazards and meet compliance requirements under the newly implemented Primary Production and Processing (PPP) Standards.

To understand current food safety practices, site visits and consultations were conducted with 154 growers and 40 processors in all major production regions across Australia. In parallel, microbial risk mapping was undertaken by collecting microbiological samples (3,762) of produce and environmental sources (including water, soil, equipment, and premises) from farms, processing facilities and retail. These samples were analysed for key target pathogens, including *Listeria monocytogenes*, *Salmonella* spp., and *Escherichia coli* to determine their prevalence and distribution. Pathogen isolates recovered from produce and environmental samples were subjected to whole-genome sequencing (WGS) to determine strain identity, diversity, persistence and regional distribution patterns.

Based on integrated findings from microbiological surveillance, industry practice assessments, and WGS analysis, a risk assessment and management framework was developed, referred to as the “Mind the W Framework.” This framework identified seven critical risk drivers for microbial contamination in leafy vegetables: Water (irrigation and produce washing), Waste from animal operations, Weather extremes, Wind from animal operations, Wildlife and animal intrusion, Washing and sanitisation practices, and Workers’ health and hygiene. The framework provided a structured, practical approach to support targeted risk assessment and mitigation across the supply chain and was widely communicated to the industry.

A key project output was the development of a Best Management Practice Guide to strengthen industry capability in microbial food safety management. The guide translates project findings into practical, science-based recommendations and integrates local industry data with internationally recognised evidence and best-practice resources. The project outputs also included two journal publications, eight technical articles, and nine scientific conference presentations, supporting dissemination of research findings and advancing knowledge in microbial food safety. The Food Safety Helpdesk provided an independent, trusted source of technical advice and support to growers, processors, regulators, and supply chain stakeholders throughout the project.

Throughout the project, grower and processor engagement was unprecedented, demonstrating a high level of openness to participatory research and risk analysis that enhanced the quality and relevance of project delivery. Stakeholder engagement activities comprised 30 presentations to industry and regulatory audiences, three webinars, and a podcast, ensuring broad and inclusive communication. These outputs provided a balanced, evidence-based representation of industry practices, challenges, and achievements, while recognising the industry’s investment in strengthening food safety systems and improving risk management. The project aligned with the Vegetable Fund Strategic Investment Plan (2022-2026) by strengthening product integrity through improved food safety systems and risk mitigation strategies. Overall, it enhanced the Australian leafy vegetable industry’s capacity to implement proactive, science-based microbial food safety systems and improved preparedness for regulatory compliance.

Keywords

Leafy vegetables, microbial risk, water, organic amendment, processing, pathogen

Introduction

Australia’s leafy vegetable (LV) industry is valued at approximately \$1.2 billion annually and is primarily domestically focused (Australian Horticulture Statistics Handbook 2024/25). LV are among the most popular fresh produce commodities, forming a staple component of healthy diets and retail fresh categories. However, due to their raw consumption and minimal processing, LV are inherently vulnerable to microbial contamination. As a result, they are unfortunately among the frequently recalled commodities within the horticulture sector, leading to significant reputational, financial, and regulatory consequences for industry.

Over the past decade, LV have been implicated in several major outbreaks and product recalls in Australia, particularly involving *Salmonella*, Shiga toxin-producing *Escherichia coli* (STEC), and *Listeria monocytogenes*. Significant incidents

include the 2016 *Salmonella* Anatum outbreak linked to bagged salad mixes, the 2021 *Salmonella* Saintpaul outbreak involving more than 580 confirmed cases, and multiple recalls of bagged spinach and mixed salad products due to *Salmonella* contamination. Improvements in microbial surveillance, traceback capability, and the adoption of whole genome sequencing (WGS) technologies by public health agencies have enhanced outbreak detection and source attribution, further highlighting the vulnerability of LV supply chains to microbial contamination.

In response to increasing regulatory scrutiny, new Primary Production and Processing (PPP) Standards for LV have been implemented from 12 February 2025, with staged implementation in some jurisdictions extending into 2026 and beyond. These standards place stronger emphasis on preventive controls and risk management practices linked to inputs, particularly water quality, soil inputs, and environmental exposures. A recent review of compliance in the vegetable industry highlighted the increasing food safety costs linked to auditing and microbiological testing (AUSVEG, 2025). As a result, the industry faces mounting regulatory and economic pressures tied to essential inputs, water and organic fertilisers, driven by continually evolving food safety standards.

The susceptibility of LV to microbial contamination is influenced by several inherent production and product characteristics. Most LV are grown in open-field environments where crops are exposed to soil, irrigation water, wildlife, flooding, dust, and other environmental factors. Their large leaf surface area, proximity to the ground, and consumption in raw or minimally processed form increase the likelihood that microbial contaminants may survive through to consumption. Contamination can occur during both preharvest and postharvest stages through contaminated irrigation water, untreated organic soil amendments, adjacent land use, worker hygiene, equipment, wash water, and processing environments. Climatic factors such as prolonged rainfall, flooding, and extreme weather events further increase contamination risks by enhancing pathogen survival and dissemination within production systems.

The future food safety outlook for the LV industry remains challenging. Climate variability, including heavy rainfall and flooding events, is expected to increase microbial contamination risks in production regions. At the same time, economic pressures associated with fertiliser, fuel, labour, and freight costs may influence production practices and potentially compromise food safety management. For example, increased fertiliser prices may encourage greater use of raw or inadequately treated animal manures, which are recognised reservoirs of foodborne pathogens.

The Hort Innovation and NSW DPIRD co-investment project VG22002 – Identifying and managing the sources and routes of microbial contamination in leafy vegetables, was commissioned in 2023 to strengthen microbial food safety systems within the industry and support industry preparedness for the implementation of the PPP Standards. The project recognised that microbial contamination risks cannot be eliminated; however, they can be significantly mitigated through evidence-based interventions, improved monitoring, and adoption of best practices. The project aimed to provide an independent assessment of current industry practices, evaluate microbial contamination risks across production and postharvest systems, and identify the most critical gaps requiring intervention.

The project focused on mapping contamination sources and transmission pathways across major production regions in Australia through microbial surveillance of produce, water, soil, equipment, and processing environments. In addition, WGS technology was applied to better characterise pathogens, determine reservoirs and persistence patterns, and improve understanding of contamination and cross-contamination within farms and packing facilities. A key objective of the project was to support industry-led microbial surveillance and empower growers to manage food safety risks using confidential, science-based evidence and technical guidance. The project also sought to develop practical tools, technical resources, and extension activities to strengthen industry capability, improve compliance with emerging regulations, and reduce the likelihood of foodborne illness outbreaks, recalls, and market disruptions.

Overall, the project represented a proactive and collaborative approach to strengthening food safety resilience within the Australian LV industry during a critical transition period. Through grower engagement, microbial risk mapping, WGS-supported investigations, and evidence-based extension, the project aims to support a stable, safe, and trusted leafy vegetable supply chain capable of meeting future regulatory and consumer expectations.

The objectives of this project were:

- Map the potential sources and routes of microbial contamination in the major LV production regions across Australia;
- Evaluate and monitor industry food safety practices and identify the potential hotspots for managing microbial contamination and cross-contamination during production and postharvest handling;
- Application of WGS technology to better characterise the pathogens, determine their reservoirs, transmission, and persistence on farms and in packing sheds;

- Develop and implement the most effective food safety control measures with the accelerated adoption across the industry by deploying learnings from other industries such as melons;
- Develop and disseminate technical resources and tools to enhance the food safety compliance of LV growers, reduce food safety incidents, product recalls and withdrawals.

Methodology

Project activity 1: Mapping the potential sources and routes of microbial contamination in Australia's major leafy vegetable production regions

A comprehensive and risk-based microbiological surveillance program was developed and implemented to identify and map the potential sources, reservoirs, and transmission routes of microbial contamination. The methodology focused on detecting enteric foodborne pathogens and indicator organisms associated with both preharvest and postharvest environments, with particular emphasis on *Salmonella* spp., Shiga toxin-producing *Escherichia coli* (STEC), and *Listeria monocytogenes*. The surveillance framework integrated microbiological testing, production practice assessments, environmental observations, and molecular characterisation approaches to establish contamination pathways and critical control points across production and processing systems.

A through-chain sampling strategy was adopted to capture microbial contamination risks from farm production through to retail. Sampling was conducted across production fields, postharvest processing facilities, wholesalers, and retail outlets to assess contamination sources and potential cross-contamination events throughout the supply chain. The study included all leafy vegetable commodities defined under the Primary Production and Processing (PPP) Standard, with a major focus on lettuce and spinach due to their production volume and historical association with foodborne illness outbreaks.

Sampling was undertaken across major leafy vegetable production regions in Australia, including Greater Sydney, Riverina and Murray (NSW), Lockyer Valley and Granite belt (QLD), Gippsland, Greater Melbourne and Murray (VIC), Hobart and Davenport (TAS), Gingin, Perth and Harvey (WA), and Virginia in Adelaide (SA). Additional production regions were also included where required to capture seasonal production variability and emerging contamination risks. The project engaged 154 growers representing diverse farming scales, production systems, and culturally diverse grower communities across Australia. Both conventional and organic production systems, field-grown and hydroponic operations, and a broad range of agronomic and postharvest handling practices were represented within the study.

The surveillance design targeted known or suspected sources of microbial contamination, including irrigation water, organic soil amendments, wildlife activity, worker contact surfaces, wash water, processing equipment, and environmental surfaces. Sampling schedules remained flexible and responsive to environmental conditions such as flooding, prolonged rainfall, and other extreme weather events that could influence microbial contamination risks. This adaptive approach enabled targeted investigations and root-cause analysis during periods of elevated risk.

A total of 3,762 samples were collected between 2023 and 2026 (Table 1). Approximately half of the samples represented environmental matrices, including agricultural water, soil, organic amendments and postharvest processing environments, while the remaining samples comprised leafy vegetable commodities collected from farms, processors, wholesalers, and retail stores. Samples included lettuce, spinach, mixed salads, herbs, Asian leafy vegetables, spring onions, kale, and other leafy vegetable commodities covered under the PPP Standard. All samples were collected aseptically using standardised protocols developed specifically for the project. Detailed metadata were recorded at the time of sampling.

Table 1. Microbial risk mapping- sample collection

Sample type	Number of samples	% of total samples
Produce	1,571	41.8%
Water	1,182	31.4%
Soil and organic amendments	494	13.1%
Premises	314	8.4%
Equipment	201	5.3%
Total	3,762	100%

Microbiological testing involved both culture-based and molecular detection methods. Samples were analysed for the presence of *Salmonella* spp., STEC, and *Listeria monocytogenes* using validated methods aligned with Australian and international standards. DNA-based molecular screening methods, including real-time polymerase chain reaction (PCR), were used for rapid detection of target pathogens. Positive samples underwent confirmatory tests (MALDI-TOF) and isolation to obtain viable pathogen isolates for further characterisation.

Confirmed pathogen isolates were subjected to whole genome sequencing (WGS) to characterise strains, determine genetic relatedness, and investigate pathogen reservoirs, persistence, and transmission pathways within production and processing environments. Comparative genomic analysis assisted in identifying recurring contamination sources, cross-contamination events, and potential epidemiological links between environmental and product isolates. The WGS data also supported traceback-style investigations and enhanced understanding of microbial ecology within leafy vegetable systems.

Microbial risk mapping data was collated and visualised using a Power BI based dashboard for rapid data access, filtering and reporting to stakeholders (Figure 1). Further information is available in Appendix I.

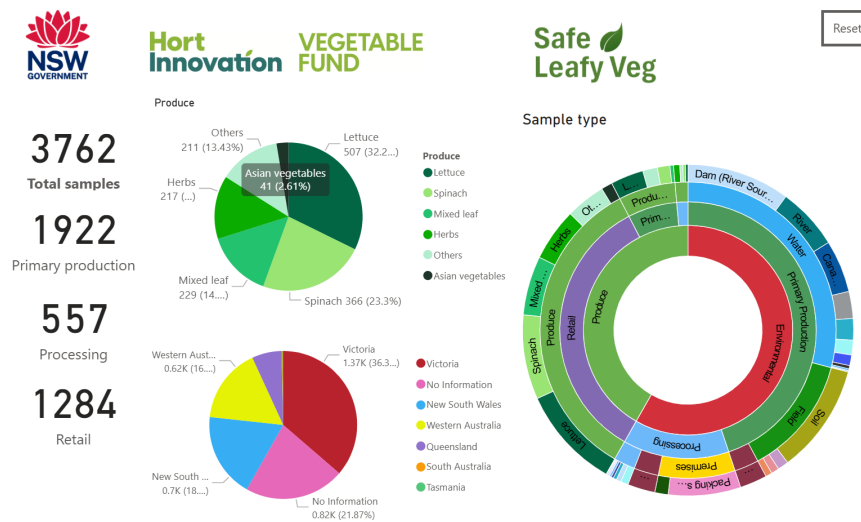


Figure 1. A snapshot of the Safe Leafy Veg Portal showing the total number of samples collected from various stages in the supply chain including the commodity type, state and sample source information.

Project activity 2: Evaluate and monitor industry food safety practices and identify the potential hotspots for managing microbial contamination and cross-contamination during production and postharvest handling.

This activity focused on evaluating and benchmarking food safety practices within the LV industry and identifying potential hotspots contributing to microbial contamination and cross-contamination during production, harvest, and postharvest handling. The activity was designed to generate a national snapshot of current industry practices and assess industry preparedness for compliance with Standard 4.2.8 - Primary Production and Processing Standard for LV (PPP Standard). The project recognised that farm location, environmental conditions, agronomic practices, harvest operations, and postharvest handling systems significantly influence microbial food safety outcomes and therefore required assessment under commercial production conditions.

The methodology adopted a “Think Nationally, Act Locally” engagement strategy, which enabled the project team to work collaboratively with growers, processors, regional industry bodies, and supply chain stakeholders across Australia’s major leafy vegetable production regions. Technical visits and on-site assessments were conducted across Greater Sydney, Riverina and Murray (NSW), Lockyer Valley and Granite belt (QLD), Gippsland, Greater Melbourne and Murray (VIC), Hobart and Davenport (TAS), Gingin, Perth and Harvey (WA), and Virginia in Adelaide (SA).

The primary methodology involved face-to-face technical visits and on-site assessments. This approach enabled the collection of high-quality primary data and facilitated grower and processor engagement. The participatory nature of the project and the willingness of growers and processors to openly discuss risks, practices, and operational challenges represented an unprecedented level of engagement, where food safety issues are often difficult to assess through direct industry participation. The project team’s long-standing relationships and more than a decade of experience in fresh produce food safety research and extension significantly contributed to the success of grower engagement activities.

The methodology integrated the industry practice review with the microbial surveillance activities undertaken in Project Activity 1. While Project Activity 2 evaluated the implementation and effectiveness of food safety systems and preventative controls, Project Activity 1 provided microbiological verification of these controls through testing of produce, water, soil, environmental, and equipment samples. The integration of operational practice data with microbial surveillance findings enabled identification of critical contamination hotspots, weaknesses in preventative control systems, and areas requiring targeted intervention.

During each technical visit, growers and processors received confidential feedback summarising observations, microbial survey results, identified gaps in best practices, and practical recommendations for improvement. These site-specific reports enabled businesses to undertake corrective actions and strengthen their food safety systems. The confidential and non-regulatory approach adopted by the project fostered trust and encouraged open discussion of food safety challenges, enabling the collection of realistic operational data from across the industry.

Project activity 3: Application of whole-genome sequencing technology to better characterise the pathogens, determine their reservoirs, transmission paths, and persistence on farms and in packing sheds.

3.1 Whole genome sequencing (WGS)

Traditional pathogen isolation and identification methods alone do not provide sufficient resolution to verify pathogen persistence, transmission pathways, or epidemiological linkages between environmental and product isolates. Therefore, the project applied next-generation WGS technologies to achieve high-resolution characterisation of foodborne pathogen isolates recovered during the microbial surveillance program. A total of 355 bacterial isolates, including 235 *Escherichia coli* isolates, 64 *Salmonella* isolates, and 56 *Listeria monocytogenes* isolates, were subjected to WGS by the University of Queensland (Appendix III). Draft genomes were assembled and analysed through comparative genomic approaches to determine genetic relatedness among isolates obtained from different production regions, environmental sources, commodities, and supply chain stages. The WGS approach enabled strain-to-strain comparisons across farms, irrigation water sources, wildlife-associated samples, processing environments, and leafy vegetable products collected over multiple crop cycles, seasons, and years. This analysis provided valuable insights into pathogen reservoirs, contamination routes, persistence patterns, and potential cross-contamination events within production and postharvest systems. The genome database generated through the project will continue to expand over time and serve as an important resource for tracking contamination trends, identifying recurring hotspots, and supporting future traceback-style investigations and risk management strategies within the leafy vegetable industry.

3.2 Microbiome analysis

In addition to pathogen genomics, the project also investigated the resident microbial communities (microbiome) associated with organic and conventional spinach and rocket. The sequencing technologies used for WGS were further applied to characterise microbial populations present on the phyllosphere of organic and conventional spinach at postharvest stages and storage. Spinach and rocket samples from conventional and organic production systems were collected from a commercial processor at before washing and after washing and sanitisation with peroxyacetic acid (PAA) as detailed in Appendix IV. Samples for microbiological analysis and 16S rRNA gene sequencing were obtained at three stages: prior to washing, after the first wash, and after the second/third wash. For each treatment, approximately 250 g of leaves were aseptically collected from multiple positions within each batch and transported to the laboratory under refrigerated conditions. Upon arrival, samples were stored at 4 °C and analysed on day 2 and after 9 days of refrigerated storage. The methodology enabled identification of dominant bacterial taxa present within samples without the need for culturing, which would have been difficult using traditional microbiological methods. Microbiome analysis provided

insights into shifts in native microbial populations during preharvest and postharvest handling. The findings generated important baseline information that may support future development of processing management strategies.

Project activity 4: Develop and implement the most effective food safety control measures with accelerated adoption throughout the industry by deploying the findings from other industries such as melons. This will include a food safety helpdesk service to help answer technical enquiries from the stakeholders, including growers, processors, regulators, and other supply chain participants.

Project Activity 4 focused on the development, implementation, and accelerated adoption of practical and evidence-based food safety control measures for the LV industry. The methodology integrated findings generated through Project Activities 1 to 3, including microbial surveillance, whole genome sequencing (WGS), microbiome analysis, and benchmarking of industry food safety practices. Based on the combined evidence generated through the project, an interim set of science-based recommendations and best management practices was developed and released in January 2025 via a technical article published by AUSVEG (Singh 2025). The recommendations prioritised interventions that demonstrated the highest potential for reducing microbial contamination risks across the leafy vegetable supply chain. In collaboration with regulators and industry stakeholders, 'Mind the W' Framework was designed and widely disseminated as a simple and effective risk assessment and management tool (Singh et al., 2025 and Singh et al., 2026).

The methodology also included direct implementation and communication of food safety interventions through industry extension and engagement activities. The project team collaborated closely with industry organisations and regional networks, including AUSVEG, AUSVEG Vic, Lockyer Valley Growers Association, NSW Local Land Services, Vegetables WA, and Protected Cropping Australia, to disseminate project findings and promote adoption of best practices. Technical information and project outcomes were communicated through grower workshops, webinars, field visits, conference presentations, industry meetings, technical articles, podcasts, and extension events. The project team delivered presentations and extension activities nationally, including at Hort Connections, Protected Cropping Australia conferences, AUSVEG workshops, and regional grower events, to increase awareness of microbial food safety risks and support industry transition into the Primary Production and Processing (PPP) regulatory framework.

Another component was the establishment and operation of a dedicated Food Safety Helpdesk service for project stakeholders. The Helpdesk served as a confidential, independent, and evidence-based technical support platform for growers, processors, auditors, exporters, importers, regulators, and other supply chain participants. The methodology recognised that many stakeholders were reluctant to publicly discuss food safety concerns due to business sensitivities, regulatory concerns, and confidentiality requirements. The Helpdesk therefore provided a trusted mechanism for stakeholders to seek practical advice and technical support in a confidential environment.

The Food Safety Helpdesk provided technical advice on a broad range of topics, including irrigation water management, microbiological testing and interpretation of results, organic amendment use, sanitation and processing practices, environmental monitoring, wildlife management, corrective actions, traceability, biosecurity issues, and compliance with PPP Standards and food safety schemes. The service also supported urgent project-related activities and provided responses to broader industry food safety and regulatory enquiries. During the project, the Helpdesk received more than 300 technical enquiries from growers, processors, regulators, auditors, and supply chain stakeholders, demonstrating strong industry demand for independent and science-based technical support.

Project activity 5: Develop and disseminate technical resources and tools to enhance the food safety compliance of LV growers, and reduce food safety incidents, product recalls and withdrawals. This will include a best practice guidance document to improve compliance with food safety standards.

This activity focused on developing and disseminating practical technical resources and tools to strengthen microbial food safety management capability within the Australian leafy vegetable (LV) industry. The methodology adopted a science-based and supply-chain-wide approach that translated project findings into practical guidance for growers and processors. A comprehensive Best Practice Guide for Microbial Food Safety Management in the Leafy Vegetable Industry was developed with a major focus on identifying and managing microbial contamination and cross-contamination risks during preharvest production, harvest, postharvest processing, storage, and distribution. Development of the guide was informed by microbial risk mapping, industry practice benchmarking, whole genome sequencing (WGS), microbiome investigations, technical site visits, and Food Safety Helpdesk enquiries generated through Project Activities 1 to 4. Technical consultation with growers, processors, retailers, auditors, regulators, and R&D providers was also undertaken to ensure that recommendations were scientifically robust, practical, and suitable for implementation under Australian production conditions.

In addition to the Best Practice Guide, a suite of practical resources and templates was developed as outlined in the output sections ahead. Particular consideration was given to ensuring that the resources were accessible and useful for growers with varying levels of technical knowledge and operational capacity. The dissemination methodology adopted a multi-channel extension and communication strategy to maximise industry engagement and adoption of project outputs. Overall, the methodology provided a systematic and evidence-based framework for translating scientific findings into practical food safety tools and extension resources that strengthened industry capability, supported regulatory preparedness, and promoted long-term improvements in microbial food safety management across the LV supply chain.

Results and discussion

Project activity 1: Mapping the potential sources and routes of microbial contamination in Australia's major leafy vegetable production regions

The microbial surveillance program exceeded its original sampling target by analysing 3,762 samples across the leafy vegetable supply chain compared with the planned target of 3,500 samples. *Escherichia coli* was the most frequently detected organism, indicating widespread environmental and faecal contamination risks within production and processing systems (Appendix I).

- Shiga toxigenic *E. coli* (STEC) was also detected mainly in environmental samples, highlighting the significance of enteric pathogen contamination risks. Lower but important prevalence rates were observed for *Listeria monocytogenes* and *Salmonella*, both of which are major foodborne pathogens associated with fresh produce outbreaks and recalls. The findings demonstrate that while pathogens occurred at comparatively lower frequencies, microbial contamination pressures across the supply chain were substantial, particularly for indicator organisms and STEC. The data further reinforced the importance of continuous microbial surveillance, risk-based preventive controls, irrigation water management, sanitation practices, and targeted interventions to minimise contamination and cross-contamination risks during production and postharvest handling of leafy vegetables.

The microbial risk mapping data demonstrated substantial variation in pathogen prevalence across different sample types within the LV sector, highlighting the importance of environmental reservoirs and operational practices in contamination dynamics.

- Water samples showed the highest overall prevalence of target pathogens suggesting it as one of the most critical transmission pathways for enteric pathogens into fresh produce systems. The high detection frequency observed in preharvest water suggests ongoing exposure of leafy vegetables to microbial contamination during crop growth, particularly under overhead irrigation systems where direct contact between water and edible plant surfaces occurs. In contrast, postharvest water showed substantially lower positive detections, indicating that postharvest water treatment and sanitisation interventions were comparatively more effective in reducing microbial loads.
- Soil and organic amendment samples showed comparatively lower pathogen prevalence, with untreated manures recording 2.5% positive detections while treated composts showed no positive detections, supporting the importance of composting process in pathogen reduction.
- Premises associated with packing and processing operations recorded a relatively high pathogen prevalence of 14.3%, while processing equipment such as conveyor belts, wash tanks, and vacuum coolers showed higher detection rates (6.9%) than field equipment (3.0%). These findings are important because postharvest environments can facilitate persistence and spread of pathogens through moisture accumulation, biofilm formation, organic matter build-up, and repeated product contact surfaces. The comparatively lower contamination observed on field equipment suggests that postharvest operations may provide more favourable environmental conditions for microbial survival and cross-contamination.
- Produce samples recorded a relatively low pathogen prevalence, which likely reflects the combined influence of multiple intervention hurdles throughout production and processing, despite contamination pressure in environmental sources.

Water quality

The analysis of 1,182 water samples demonstrated a strong relationship between generic *E. coli* populations and the prevalence of foodborne pathogens in irrigation and water sources.

- Most water samples (62.8%) contained *E. coli* populations between 1–100 CFU/100 mL, while 13.9% of samples

exceeded 100 CFU/100 mL. *E. coli* is widely recognised as an indicator organism for faecal contamination and is commonly used to assess the microbiological quality of agricultural water.

- The data showed that as *E. coli* populations increased, the probability of detecting enteric pathogens also increased substantially. For example, detection of *E. coli* carrying the *eae* gene increased from 12.2% in water samples containing <1 CFU/100 mL to 94.0% in samples exceeding 100 CFU/100 mL. Similarly, Shiga toxinogenic *E. coli* (STEC) prevalence increased markedly from 2.2% to 64.3% across the same *E. coli* population ranges. The relationship between increasing *E. coli* populations and detection of *Salmonella* species and *Listeria monocytogenes* was evident. *Salmonella* prevalence increased from 0.4% in low *E. coli* water samples to 7.1% in samples containing >100 CFU/100 mL, while *Listeria monocytogenes* increased from non-detectable levels to 12.5% within the same water quality categories.

These findings provide strong scientific evidence that elevated *E. coli* levels in irrigation water are associated with significantly greater microbial contamination risks and can serve as an important predictive indicator of pathogen presence in agricultural water systems.

- Multiple co-occurrence events were also identified, including STEC with *Salmonella* (18 samples), STEC with *Listeria monocytogenes* (19 samples), and simultaneous detection of all three pathogens in two samples. These findings demonstrate that elevated *E. coli* levels are not only associated with a greater probability of pathogen presence but also with increased likelihood of multi-pathogen contamination events, indicating substantial faecal and environmental contamination pressure within irrigation water systems. The results reinforce the importance of *E. coli* as a practical indicator organism for irrigation water quality assessment and highlight the need for stringent water management, microbiological monitoring, and preventive interventions to minimise pathogen introduction into leafy vegetable production systems.

Monitoring of irrigation and surface water sources over two years demonstrated substantial seasonal variation in microbiological water quality, with surface water systems showing greater fluctuations in *E. coli* populations compared with protected water sources such as rainwater tanks and farm dams. Water quality consistently deteriorated during the summer production period (December to February), when water sources exceeded the 100 CFU/100 mL *E. coli* threshold, indicating increased microbial contamination risks. Elevated summer temperatures, reduced water flow and increased organic matter loads potentially led to higher microbial populations during this period. The data also showed that extreme weather events, particularly heavy rainfall and flooding, significantly impacted water quality by causing sharp increases in *E. coli* levels across multiple surface water systems. Flooding and runoff events can transport faecal material, sediments, organic matter, and pathogens from surrounding agricultural land, livestock operation, wildlife habitats, and urban environments into irrigation water sources, thereby increasing pathogen survival and dissemination risks. These findings highlight the vulnerability of surface water sources to seasonal and environmental influences and reinforce the importance of continuous microbiological monitoring, weather-responsive risk assessments, and implementation of preventive water management strategies during high-risk periods.

Project activity 2: Evaluate and monitor industry food safety practices and identify the potential hotspots for managing microbial contamination and cross-contamination during production and postharvest handling.

Leafy vegetable farm operations characteristics: The project engaged 154 leafy vegetable growers representing a diverse cross-section of production systems, crop types, farming scales, and geographic regions across Australia.

- Growers produced a range of commodities including leafy head crops such as lettuce and cabbage (29.2%), baby leaf products including baby spinach and mixed salads (12.3%), and a combination of both baby leaf and leafy head crops (26.6%). Other commodities such as herbs, Asian vegetables, spring onions, and kale accounted for 31.8% of production.
- Participation was geographically distributed across major production regions, with the highest representation from Vic (24.7%), NSW (22.7%), Qld (19.5%), and WA (16.2%). Large-scale farms (>10 hectares) represented 42.2% of growers, while small-scale (<2 hectares) and medium-scale (2–10 hectares) operations accounted for 37.0% and 20.8%, respectively.
- Conventional production systems dominated the industry (92.9%), with field production representing 74.7% of operations and hydroponic production accounting for 25.3%.
- Adoption of Global Food Safety Initiative (GFSI)-certified food safety schemes was relatively high overall (61%); however, certification was strongly associated with farm scale, with all large-scale growers certified compared

with only 12.4% of medium-scale and 5.3% of small-scale growers engaged in this project.

Key industry practice information on inputs (water and soil) for field production (n=115) of leafy vegetables

The industry practice data involving 115 field-based leafy vegetable growers provided important insights into current preharvest food safety practices and highlighted several areas associated with increased microbial contamination risk.

- Surface water sources, including rivers, farm ponds and creeks were the predominant sources of irrigation water and were used by 75.6% of growers. Only a small proportion of growers relied exclusively on groundwater (7.0%), while 17.4% used a combination of surface and groundwater sources. From a microbial food safety perspective, reliance on surface water is significant because such water systems are inherently vulnerable to contamination from environmental runoff, flooding, wildlife activity, livestock access, upstream agricultural activities, and sediment disturbance. Seasonal fluctuations, particularly during summer and following heavy rainfall events, can further deteriorate microbiological water quality.
- Only 13.1% of growers reported applying any form of irrigation water treatment, mainly coarse filtration systems, while the majority (86.9%) used untreated water directly for crop irrigation. Coarse filtration can assist in reducing sediment loads and improving water quality, particularly where microbial contaminants are associated with suspended organic matter and particulates. However, the limited adoption of water treatment practices indicated that irrigation water management remains a major opportunity for improving food safety outcomes within the industry.
- The data showed that overhead sprinkler irrigation was the dominant irrigation method, used by 95.7% of growers, with only a small number using a combination of overhead and drip irrigation systems. This finding is particularly important because overhead irrigation directly wets the edible portions of leafy vegetables and therefore increases the likelihood of transferring microbial contaminants from irrigation water onto crop surfaces. Leafy vegetables, particularly baby leaf products and spinach, possess large surface areas and complex leaf structures that can facilitate attachment and survival of microorganisms. In contrast, drip irrigation systems are generally considered lower risk because they minimise direct contact between irrigation water and edible plant tissues.
- Most growers (87.8%) reported conducting microbiological testing of irrigation water, reflecting increasing awareness of irrigation water risks. However, the survey also indicated that 12.2% of growers did not undertake any microbiological testing, highlighting ongoing variability in industry capability and risk management practices. The findings reinforced that irrigation water quality, water source protection, and irrigation method selection are critical components of microbial food safety management within leafy vegetable production systems.

The project identified several practical water quality improvement strategies implemented by growers to reduce microbial contamination risks associated with irrigation water. Growers managed water quality through sediment reduction and staged water handling systems, particularly by storing irrigation water pumped from rivers in farm ponds to allow suspended sediments and organic matter to settle before use. Following sediment settling, some growers applied coarse filtration systems with frequent backflushing to remove remaining particulate matter and maintain filtration efficiency. The data demonstrated that these interventions substantially improved water quality, particularly in comparison with untreated river water sources that showed consistently high *E. coli* populations and greater seasonal fluctuations. In some cases, water used in overhead sprinkler systems recorded *E. coli* levels ranging from non-detectable to less than 3 CFU/100 mL, with no detection of target pathogens, demonstrating the effectiveness of integrated water management approaches. Additional interventions adopted by growers included lining water storage dams with plastic to minimise sediment disturbance and contamination, continuous aeration of stored water, fencing of dams to restrict wildlife and livestock access, and protection of water sources from runoff and environmental contamination. These practices highlighted the industry's increasing adoption of risk-based water management strategies to improve irrigation water quality and reduce microbial contamination risks within leafy vegetable production systems.

- The industry practice data further highlighted the widespread use of organic soil amendments containing animal waste within leafy vegetable production systems, with approximately half of growers (50.4%) reporting their use. Among these growers, treated compost was the most commonly applied amendment (56.8%), demonstrating a relatively strong industry awareness of composting and pathogen reduction practices. Properly managed composting processes involving adequate temperature, moisture, and turning can substantially reduce pathogen survival within organic amendments.
- In contrast, 24.1% of growers reported using untreated poultry litter or cattle manure, while a further 18.9% used a mixture of treated and untreated amendments. Although untreated animal manures can provide

agronomic and economic benefits, they are recognised reservoirs of enteric pathogens. Their use therefore presents a potential contamination risk if not managed appropriately.

- Most growers applied organic amendments prior to planting through soil incorporation (91.4%), which is generally considered a lower-risk practice because it allows time for pathogen die-off before harvest. Only a small proportion of growers applied amendments both before and after planting through side-dressing or top-dressing practices, which may present greater contamination risks due to closer proximity to harvest.
- Importantly, the data revealed that the use of untreated organic amendments was strongly associated with smaller farming operations, with 85.7% of untreated manure use occurring on farms smaller than two hectares. This finding suggests that small-scale growers may face greater challenges in accessing treated compost products, advanced waste treatment systems, or formal food safety support programs. Smaller operations may also have reduced technical capability, financial resources, and access to certified food safety systems compared with larger commercial enterprises. These findings suggest the need for targeted support, practical guidance, and affordable risk management solutions for small and medium-sized growers to improve compliance with food safety requirements.

Overall, the survey demonstrated that irrigation water management, overhead irrigation practices, microbiological water testing, and management of organic soil amendments represent key preharvest risk areas requiring continued industry investment, technical guidance, and evidence-based intervention strategies to strengthen microbial food safety outcomes across the Australian leafy vegetable industry.

Farm location vulnerabilities to livestock operations, extreme weather and wildlife pressure for field production (n=115) of leafy vegetables.

Environmental and geographical vulnerabilities that may increase microbial contamination risks within production systems.

- Flooding and heavy runoff exposure represented the most common vulnerability, affecting 30.4% of growers, followed closely by wildlife and animal intrusion risks (29.6%). Wildlife intrusion alone was identified by 15.7% of growers, while proximity to livestock operations within one kilometre of production fields affected 13.9% of growers.
- A further 8.9% of growers reported combined risks associated with both flooding and nearby livestock operations, which may substantially increase the likelihood of faecal contamination entering production areas through runoff, floodwaters, dust movement, wildlife transfer, or direct environmental exposure. These environmental factors are highly relevant because livestock, wildlife, and contaminated runoff are recognised reservoirs and transmission pathways for foodborne pathogens such as *Salmonella*, STEC, and *Listeria monocytogenes*.
- Dust storms and bushfires were also identified as emerging environmental risks by 9.6% and 7.8% of growers, respectively. Bushfire events may indirectly increase contamination risks through displacement of wildlife populations into cropping areas, while dust storms can facilitate movement of soil particles, faecal material, and microorganisms across production environments.

The data showed considerable variability in the implementation of mitigation measures designed to reduce environmental contamination risks.

- Growers located near livestock operations showed the highest adoption of mitigation strategies, with 91.3% implementing measures such as fencing and windbreaks to minimise animal intrusion and dust transfer. In contrast, mitigation measures for flooding-related risks were comparatively limited, with only 11.4% of growers exposed to flooding and runoff implementing interventions such as drainage systems, levees, raised beds, or field contouring. Even lower adoption rates were observed where growers faced combined flooding and livestock risks, with only one grower out of ten reporting implementation of multiple mitigation measures.
- Wildlife intrusion risks also remained poorly managed, with none of the growers reporting wildlife-only risks implementing effective control strategies. Inadequate mitigation of these environmental vulnerabilities may increase the probability of pathogen introduction into irrigation water, soil, and crop production systems, particularly during extreme weather events. The findings highlight that environmental and climate-related risks are becoming increasingly important components of microbial food safety management within leafy vegetable systems and reinforce the need for targeted guidance, infrastructure investment, and practical interventions to strengthen industry resilience against flooding, wildlife intrusion, and other external contamination pressures.

Processing operations characteristics for LV (n=40)

Technical visits to LV processing facilities provided important insights into postharvest handling systems and food safety management practices within the industry.

- Facilities processing both baby leaf and leafy head products represented the largest proportion of processors (37.5%), followed by processors specialising in baby leaf products such as baby spinach and mixed salads (25%) and leafy head vegetables including lettuce and cabbage (22.5%). Processing operations were concentrated in Victoria, which accounted for 47.5% of facilities, reflecting the state's significant role in the LV supply chain. Queensland and Western Australia also represented important processing regions, accounting for 20% and 15% of facilities, respectively.
- Postharvest cooling was widely adopted across the industry, with 95% of processors implementing cooling systems to manage product temperature and maintain shelf-life. Vacuum cooling was the dominant cooling method, used by 72.5% of growers/processors, while 23.5% relied on air-cooling systems. Rapid postharvest cooling is critical for reducing respiration rates, maintaining product quality, and limiting microbial growth during storage and distribution. Vacuum cooling, in particular, is considered highly effective for LV because it enables rapid and uniform temperature reduction throughout the product.
- Approximately half of the processors (52.5%) undertook postharvest washing and sanitisation operations, particularly for baby leaf products, herbs, and mixed salads that require washing prior to packaging. Among these processors, 90.5% used sanitisers in wash water systems, demonstrating strong industry recognition of the importance of preventing microbial cross-contamination during processing.
- Peroxyacetic acid (PAA) was the most commonly used sanitiser (63.2%), followed by chlorine-based sanitisers (36.7%). Effective wash water sanitisation is critical because organic matter during produce washing can rapidly reduce water quality and facilitate pathogen transfer between contaminated and uncontaminated produce. The use of sanitisers therefore plays an important role in maintaining microbiological quality and reducing cross-contamination risks within recirculated wash systems.
- Despite the widespread adoption of cooling and wash water sanitation practices, relatively few processors (22.5%) reported implementing regular environmental monitoring and management programs. This finding is significant because processing environments and equipment can act as reservoirs for persistent pathogens such as *Listeria monocytogenes*, particularly in wet and high-moisture environments. The comparatively low adoption of environmental monitoring programs highlights an important opportunity for strengthening postharvest food safety systems and improving contamination prevention and verification practices within leafy vegetable processing facilities.

Project activity 3: Application of whole-genome sequencing technology to better characterise the pathogens, determine their reservoirs, transmission paths, and persistence on farms and in packing sheds.

3.1 Whole-genome sequencing (WGS)

WGS has emerged as a transformative tool in fresh produce food safety by providing high-resolution genomic data for the characterisation, tracking, and risk assessment of foodborne pathogens and indicator organisms within complex horticultural production systems. WGS enables comprehensive analysis of pathogen genomes, allowing precise discrimination between closely related strains and facilitating detailed phylogenetic and epidemiological investigations.

WGS was undertaken on a collection (355) of environmental and produce-associated bacterial isolates comprising 235 *Escherichia coli*, 64 *Salmonella* spp., and 56 *Listeria monocytogenes* isolates recovered during the project (2023-2025). The majority of isolates were obtained from irrigation and environmental water sources, suggesting the critical role of agricultural water as a primary ecological reservoir and dissemination pathway for foodborne pathogens and indicator organisms. The WGS-derived sequence typing data substantially enhanced understanding of pathogen transmission ecology and source attribution within horticultural environments (Appendix III).

Genomic relationships identified among isolates recovered from distinct geographic locations and sampling periods demonstrated complex transmission dynamics involving environmental reservoirs, hydrological connectivity, wildlife activity, and farm management practices. Several linkages and transmission pathways were elucidated through phylogenetic analyses, highlighting the role of surface water systems in the persistence and dissemination of *E. coli* and *Salmonella* populations. The longitudinal nature of the dataset further enabled assessment of strain persistence and seasonal re-emergence, providing important insights into microbial ecology and environmental survival mechanisms.

relevant to fresh produce safety risk assessment frameworks.

In addition to source tracking and transmission analysis, WGS proved highly valuable for in-depth characterisation of virulence-associated determinants and antimicrobial resistance (AMR) profiles within the isolate collection. Genomic screening identified the presence of virulence genes and putative AMR-associated determinants, allowing a more refined assessment of the pathogenic potential and public health significance of environmental isolates. Importantly, the sequencing outcomes facilitated development of several region-specific case studies that were communicated directly to growers and industry stakeholders as part of targeted extension and risk mitigation activities. These included investigations supporting potential wildlife-associated contamination pathways involving kangaroos and reptiles, as well as evidence linking livestock proximity and movement patterns with environmental contamination events. The WGS program demonstrated the utility of genomics-based surveillance as a powerful tool for microbial source tracking, environmental risk profiling, and evidence-based food safety management within horticultural production systems.

3.2 Microbiome analysis of spinach and rocket leaves

The composition of leafy vegetable microbiomes is strongly influenced by preharvest factors, including crop species, cultivar, climate, soil characteristics, irrigation water quality, organic amendments, wildlife activity, and farming systems. Organic and conventional production systems often support distinct microbial communities due to differences in nutrient inputs, soil management practices, and agrochemical use. Environmental reservoirs such as soil, irrigation water, livestock, and wildlife contribute microorganisms that colonise leaf surfaces and shape microbiome structure throughout crop growth. Following harvest, postharvest handling and processing practices can substantially modify the phyllosphere microbiome.

Postharvest processing removes or suppresses certain microbial populations while allowing others to survive and become dominant. Sanitisers such as chlorine and PAA often reduce total microbial loads but may have differential effects on individual taxa, resulting in shifts in community composition rather than uniform microbial reduction. Understanding how preharvest and postharvest factors shape microbial communities is therefore essential for developing microbiome-informed food safety strategies. Advances in microbiome analysis provide opportunities to identify microbial indicators of contamination risk, understand pathogen interactions within complex microbial ecosystems, and develop targeted interventions that promote beneficial microflora while reducing the survival and transmission of foodborne pathogens in fresh produce supply chains.

Microbiome analysis of organic and conventional spinach and rocket leaves washed and sanitised using a PAA-based sanitation system is presented in Appendix IV. Key findings are as follow:

- Microbiome analysis demonstrated that washing cycle (double or triple) significantly influenced microbial load. Triple washing was more effective than double washing for both spinach and rocket, resulting in lower increases in total plate counts during one week of refrigerated storage.
- As PAA concentrations remained above recommended sanitisation thresholds throughout the washing process, the improved microbial outcomes associated with triple washing are likely attributable to enhanced physical removal of microorganisms rather than differences in sanitiser concentration. These findings indicate that the number of washing cycles is a critical operational parameter influencing washing efficacy and subsequent product shelf life.
- Substantial differences in microbial community composition were observed between crop types and production systems. Spinach exhibited greater genus-level diversity than rocket, suggesting a more complex and heterogeneous phyllosphere microbiome. In contrast, rocket microbiomes were frequently characterised by low diversity and dominance of one or two bacterial genera, particularly under organic production systems.
- Organically grown spinach and rocket were associated with a higher relative abundance of Firmicutes, with *Exiguobacterium_A* and *Bacillus_A* representing dominant taxa, respectively. Conversely, conventionally produced samples were predominantly colonised by Proteobacteria, particularly *Pseudomonas_E*.
- Prior to washing, organic spinach showed elevated levels of *Exiguobacterium_A*, whereas organic rocket was consistently dominated by *Bacillus_A*. Conventional spinach and rocket samples were frequently dominated by *Pseudomonas* spp., especially following washing and subsequent cold storage.
- Peroxyacetic acid washing resulted in an immediate reduction in total bacterial abundance; however, its effects on microbial community composition were selective rather than uniform. Washing substantially reduced the relative abundance of *Exiguobacterium_A*, particularly in organic spinach and conventional rocket. In contrast,

Pseudomonas_E demonstrated considerable tolerance to the washing process and, in several instances, increased in relative abundance following successive wash cycles, most notably in conventional spinach.

- *Bacillus_A* increased markedly in relative abundance after washing in both organic and conventional rocket. This response likely reflects the inherent resistance of *Bacillus* species to chemical sanitisation, including the persistence of spores and stress-tolerant vegetative cells. These findings suggest that while PAA-based washing effectively reduces overall microbial loads, its capacity to control *Bacillus* may be limited, even at concentrations exceeding 100 ppm.
- The results support the adoption of triple washing as a preferred commercial practice for spinach and rocket processing, while highlighting the need for alternative or complementary interventions to improve control of resilient bacterial populations and optimise microbial quality outcomes.

Project activity 4: Development of best management practices and industry resources

A major focus of the project was the translation of scientific findings into practical outcomes that could be readily adopted by industry to strengthen microbial food safety management. The project generated one of the most comprehensive datasets on microbial food safety in Australian leafy vegetable production systems, encompassing environmental monitoring, irrigation water quality assessments, pathogen prevalence surveys, whole genome sequencing (WGS), microbiome analyses, processing studies, and industry practice evaluations. These findings were synthesised and translated into a comprehensive Best Management Practice (BMP) Guide for growers and processors (Appendix V). The BMP Guide provides science-based, risk-based recommendations covering critical control points throughout the supply chain, including irrigation water management, soil amendments, wildlife and livestock exclusion, harvest operations, processing sanitation, environmental monitoring and verification activities. Importantly, the guide incorporates Australian industry data generated through the project, ensuring that recommendations are relevant, achievable and tailored to local production systems and regulatory requirements.

In addition to the BMP Guide, a broad suite of technical resources was developed to support industry capability building and continuous improvement in food safety management (Appendix VI). A food safety management statement (FSMS) template was developed for growers and processors to conduct and record risk assessment and management in alignment with new PPP standard (Appendix XIV). These resources included technical articles and practical guidance documents designed to assist businesses in implementing evidence-based food safety practices. Findings from pathogen surveillance, WGS-based source attribution studies, microbiome analyses and postharvest intervention trials were translated into practical recommendations that addressed key industry concerns regarding water quality, environmental reservoirs, pathogen persistence and processing efficacy. Together, these resources provide support towards proactive risk management, facilitating compliance with evolving regulatory requirements and strengthening the industry's capacity to prevent and respond to microbial food safety risks.

Project activity 5: Communication, extension and industry engagement

Communication, extension, and stakeholder engagement were fundamental components of the project and were integrated throughout all stages of project delivery. The project delivered an extensive communication, extension, and stakeholder engagement program that ensured research findings were translated into practical outcomes for the LV industry. A total of 53 communication outputs were generated, including refereed journal publications, technical articles, conference presentations, industry workshops, webinars, and a podcast. The communication strategy was designed to engage stakeholders across the entire leafy vegetable supply chain, from primary production through to retail, regulation, and research. This broad engagement ensured that project findings contributed not only to scientific advancement but also to practical improvements in food safety management and industry capability.

The project successfully engaged a diverse range of stakeholder groups, reflecting a whole-of-supply-chain approach to food safety improvement. Stakeholders included growers, processors, retailers, regulators, industry organisations, researchers, and policymakers. The geographical reach of the project was extensive, covering all major leafy vegetable production regions across Australia and extending internationally. Communication activities were delivered across the country, ensuring that findings were shared with industry participants operating under a wide range of climatic, environmental, and production conditions. International presentations and collaborations in New Zealand and Spain further increased the visibility and impact of the project. This broad geographic coverage ensured that project outcomes were relevant to diverse horticultural production systems and contributed to both national and international food safety

discussions. A notable strength of the project was the diversity of communication channels used to disseminate findings. Activities included:

- 2 refereed journal publications
- 8 technical articles and industry publications
- 9 scientific conference presentations
- 30 industry and regulator presentations
- 3 webinars
- 1 industry podcast

This mix of scientific, industry-focused, regulatory, and digital communication platforms maximised stakeholder reach and ensured that information was accessible to audiences with varying technical backgrounds. The strong emphasis on industry presentations demonstrates the project's commitment to promoting adoption of research findings and supporting practical implementation of food safety improvements throughout the sector.

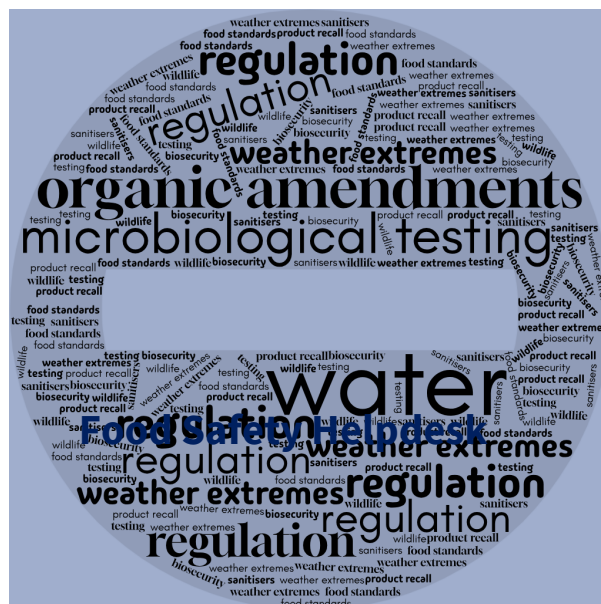
The topics communicated through the project reflected the breadth and complexity of contemporary fresh produce food safety challenges. Major themes included microbial food safety risk management, irrigation water quality, pathogen ecology and source attribution, environmental monitoring, emerging food safety hazards, regulatory compliance, and the impacts of extreme weather events such as flooding, bushfires, and dust storms. Significant attention was also given to STEC risk management, implementation of new food safety standards, and building industry resilience through science-based decision making. These communication and extension activities have strengthened industry awareness, enhanced regulatory preparedness, improved stakeholder understanding of microbial risks, and supported the adoption of evidence-based food safety practices across the LV sector.

The Food Safety Helpdesk Service

It was a highly valued and impactful component of the project, providing growers, processors, industry service providers, and other stakeholders with access to independent, science-based technical advice on a wide range of microbial food safety issues. Throughout the project, the service functioned as a central point of contact for technical enquiries and supported stakeholders in interpreting food safety requirements, assessing risks, and implementing practical mitigation measures. The Project Leader responded to over 300 enquiries received via emails, telephone calls, text messages, online meetings, and informal consultations at industry events. Where possible, records of enquiries and responses were maintained to enable analysis of emerging trends, recurring challenges, and industry knowledge gaps. The helpdesk service complemented formal extension activities by providing timely, confidential, and tailored support to individual businesses facing specific food safety concerns.

An important feature of the helpdesk service was its confidential and trusted nature. Growers and processors were often willing to discuss sensitive food safety issues, including positive microbiological results and potential contamination incidents, knowing that advice would be provided independently and confidentially. In many instances, the helpdesk facilitated follow-up support to assist businesses with risk assessments, interpretation of laboratory findings and engagement with supply chain partners or regulators. This confidential support mechanism helped build trust with industry participants and encouraged proactive management of food safety risks before they escalated into larger commercial or regulatory issues.

Growers and processors: The helpdesk played an important role in supporting industry preparedness and compliance with the new PPP Standards. A substantial proportion of enquiries related to interpretation and implementation of the standards, including requirements for preharvest water quality monitoring, environmental assessments and implementation schedules. Growers and processors frequently sought advice on irrigation water testing programs, management of microbial contamination risks associated with water sources, and interpretation of laboratory results. Enquiries relating to organic amendments, wildlife, extreme weather, recalls, and postharvest sanitisation were common, reflecting industry concerns regarding balancing sustainability objectives with food safety obligations.



Emergency response: The helpdesk served as an important mechanism for identifying and responding to emerging food safety issues affecting the industry. The service facilitated rapid communication between growers, processors, retailers, regulators, and researchers, providing timely technical advice and evidence-based risk assessments. Key emergency response activities included:

- **STEC Recall (March 2025):** Provided technical support to industry and regulators on recall, incident investigation, and risk assessment. Delivered follow-up extension activities through VegNET, FSANZ Industry Roundtable on STEC, a national webinar hosted by Coles, grower-focused technical sessions organised by Woolworths and a technical article on STEC published.
- ***Bacillus* recall (Singapore, August 2025):** Supported an Australian processor in reviewing processes and identifying potential contamination pathways. Subsequent microbiome investigations generated valuable insights into *Bacillus* contamination risks in packaged salads and brought together all other processors facing similar issues.
- **Tomato Potato Psyllid (TPP) Biosecurity Response:** Provided technical advice to state biosecurity agencies reviewing interstate movement protocols, helping align regulatory requirements with current postharvest handling practices.
- ***Salmonella* detection on a leafy vegetable farm:** Assisted grower with site investigations and risk assessments. Whole genome sequencing linked the isolate to wildlife sources on the property, supporting evidence-based risk mitigation strategies.
- **In response to flooding events (2023-2026),** growers were supported through risk assessments and microbiological testing in Greater Sydney, Lockyer Valley and Gippsland regions.

Regulators liaison: The helpdesk played a critical role in fostering engagement between the industry, the FSANZ-led Implementation Subcommittee for Food Regulation (ISFR), food regulators, and the Hort Standards Implementation Working Group. Through regular updates and technical briefings (listed in project outputs), the project leader provided regulators with current insights into industry practices, emerging food safety challenges, and the practical realities of implementing food safety standards on-farm. These engagements helped regulators better understand the constraints faced by growers, including factors beyond direct control, the limited availability of scientific evidence to support certain compliance requirements, and the increasing cost pressures associated with managing key food safety inputs such as irrigation water and soil amendments.

Dedicated technical sessions were also delivered to regulatory agencies including the NSW Food Authority, Agriculture Victoria, Biosecurity Tasmania, PIRSA, and WA Health, among others. In addition, the Helpdesk provided ongoing technical support to regulators in the development and refinement of guidance materials, risk-management resources, and technical advisory documents. This included direct contributions to guidance development initiatives led by agencies such as the NSW Food Authority and Agriculture Victoria. These activities strengthened communication between industry and regulators, promoted evidence-based decision-making, and supported the consistent implementation of food safety standards across the Australian leafy vegetable supply chain.

Future R&D agenda: Beyond its immediate advisory function, the Food Safety Helpdesk Service played a strategic role in shaping the future R&D agenda. Analysis of enquiry trends provided direct insight into industry priorities, emerging risks, and areas where additional scientific evidence or practical guidance was required. Topics such as irrigation water management, environmental reservoirs of pathogens, wildlife-associated contamination, wash water sanitisation, STEC risk management, and implementation of the PPP Standards emerged as key themes requiring ongoing research and extension support. As a result, the helpdesk served not only as a valuable industry support mechanism but also as an effective knowledge exchange platform, enabling two-way communication between researchers and industry and ensuring that future R&D activities remain aligned with real-world food safety challenges facing Australian fresh produce businesses.

Outputs

Table 2. Output summary

Output	Description	Detail
Program logic and monitoring and evaluation plan	Project management tool for project team, Hort Innovation and DPIRD	Submitted to Hort Innovation at milestone MS102 and approved.
Project risk register and how risks will be managed	Project delivery risks identification and mitigation plan for Hort Innovation and DPIRD	Submitted to Hort Innovation at milestone MS102 and approved.
Stakeholder engagement plan	Project outputs delivery schedule to target stakeholders	Submitted to Hort Innovation at milestone MS102 and approved.
Project reference group (PRG)	To provide strategic direction and oversight to project delivery involving stakeholder representatives.	The PRG was constituted with representatives of LV growers, processors, food safety experts, AUSVEG, Hort Innovation and DPIRD. The PRG meetings were held (20 Oct 2023 and 22 Aug 2025), minutes produced and followed up as per contract.
A presentation to the Vegetable Strategic Investment Advisory Panel (SIAP)	To review the project progress and determine the continuation of project to the second stage.	A technical presentation on the project progress was delivered to the Vegetable SIAP on 26 March 2024. SIAP approved the project progression to the second stage.
A review of industry food safety practices and assessment of potential sources and routes of microbial contamination in the major LV production regions	The industry practice reviewed across major LV production regions across Australia through technical visits to production and processing facilities.	The project engaged 154 growers and 40 processors/packers to review their food safety practices with a focus on production and processing inputs (Appendix II).
Microbial surveillance data and trends to inform the food safety management along the supply chain	Microbial risk mapping conducted across the supply chain by collecting and analysing microbiological amples	A total of 3,762 samples were collected and analysed for target pathogens (<i>Listeria monocytogenes</i> , <i>Salmonella</i> and <i>Escherichia coli</i>) to inform their prevalence and distribution in production and processing environments and potential transfer to supply chain.
Whole-genome sequence (WGS) and data-driven tools to accelerate the industry's food safety risk forecast and management approach	Data from industry practice, risk mapping and WGS were collated and analysed to determine the major sources and routes of	WGS of 355 isolates revealed pathogen diversity, potential reservoirs and transmission patterns in the production and processing environments. WGS approach was powerful to decipher pathogen transmission previously unknown and was used to develop the 'Mind the W' framework for risk assessment and management.

	microbial contamination and finding intervention points along the supply chain.	
A food safety helpdesk service	To address technical enquiries from the stakeholders, including growers, processors, regulators, and other supply chain participants	Over 300 technical enquiries were received and addressed through the project. LV growers, packers and regulators were three prominent stakeholders enquiring on a range of topics linked to production, processing and product recalls.
Technical resources	To evaluate, monitor and support leafy vegetable producers to enhance food safety capacity, including a best practice guidance document.	A best management practice guide has been developed to support the LV industry in preventive risk management and enhance their compliance with food safety standards (Appendix VI)
Two peer-reviewed journal articles	Two articles published in peer-reviewed reputed journals.	1. Rood L, Kocharunchitt C, Bowman C, Stanley R, Ross T, Danyluk M, Warriner K, Singh SP, Eyles A (2025). Potential for in-field pre-harvest control of foodborne human pathogens in leafy vegetables: identification of research gaps and opportunities. Trends in Food Science and Technology, 158, 104928. (Appendix VI) 2. Singh SP (2023) Flooding adversely affects fresh produce safety. Microbiology Australia 44, 185-189. https://doi.org/10.1071/MA23054 (Appendix VII)
Six technical articles will be published in industry magazines over the life of the project	Technical articles covered a range of topics including food safety risk management in leafy vegetables, 'Mind the W' Framework, and response to STEC recalls and bushfires.	1. Singh SP, Dinsdale J and Hall C. 2026. Safe Leafy Veg - Mind the W Framework. WA Grower Autumn 2026, 54-56 (Appendix XII) 2. Singh SP, 2025. Shiga toxin-producing <i>Escherichia coli</i> (STEC) contamination of LV and risk management. April 2025, Primefact PUB25/305 (Appendix IX) 3. 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 (Appendix XI) 4. Singh SP, 2025. The Safe Leafy Veg project provides insights into microbial risks and their management. AUSVEG Knowledge Hub Feb 2025 (Appendix X) 5. Singh SP, 2025. New food safety standards for leafy vegetables, berries and melons from Feb 2025. Protected Cropping Australia (PCA) Growing Undercover Newsletter, Jan 2025 6. Singh SP, 2025. Microbial food safety risks in leafy vegetable production in protected cropping systems. PCA Growing Undercover Newsletter, Jan 2025 7. Singh SP, 2024. Tracking and cutting down microbial contamination in leafy vegetables. Vegetable News Jan 2024 (Appendix XI)

		8. Singh SP, 2023. Microbial food safety risks associated with producing and processing fresh produce in bushfire-affected regions December 2023, Primefact PUB23/1247 (Appendix VIII)
Food safety management statement (FSMS) template	A FSMS template was developed for growers and processors to conduct and record risk assessment and management in alignment with new PPP standard.	Appendix XIV
Conferences presentations		1. Singh SP, 2025. Fresh produce safety in a circular economy. International Fresh Produce Safety Symposium Sydney 29 July 2025 (invited). 2. Singh SP, 2025. Food safety risk management in protected cropping systems. Protected Cropping Australia Conference Adelaide on 28 July 2025. 3. Singh SP, 2025. Scorched and swept: bushfires and dust storms implications on fresh produce safety. IAFP European Food Safety Symposium, Madrid, Spain 6-8 May 2025 (keynote). 4. Singh SP, 2025. Water quality challenges for the production and processing of safe leafy vegetables. Australian Food Microbiology Conference, Sydney 5-6 Mar 2025 (invited) 5. Singh SP, 2024. Postharvest environmental monitoring. Challenges for Postharvest Food Safety Systems Workshop at the ISHS International Postharvest Symposium, Rotorua, New Zealand 11-13 Nov 2024 (invited) 6. Singh SP, 2024. Food safety of fresh produce: striking a balance between compliance, sustainability and profitability. ISHS International Postharvest Symposium, Rotorua, New Zealand 11-13 Nov 2024 (oral presentation) 7. Singh SP, 2024. Towards convergence of produce safety science, standards, practice and profitability. International Fresh Produce Safety Symposium, Sydney on 21-22 August 2024 (invited) 8. Singh SP, 2024. Extreme weather events impact microbial food safety of field-grown leafy vegetables. Australian Food Microbiology Conference, Melbourne 13-14 Mar 2024 (invited) 9. Singh SP, 2023. Were toxic weed (thornapple) leaves on the horizon scan for emerging food safety hazards in leafy salads? Australian Institute of Food Science and Technology (AIFST) Convention 24-25 June 2023 (Invited).
Presentations at industry and regulators meetings/forums	Technical presentations delivered to a variety of stakeholders: 1. LV growers workshops in Lockyer Valley,	1. Singh SP, 2026. Fresh produce safety – on and beyond the horizon. Woolworths Suppliers Technical Forum, Sydney 19 May 2026. 2. Singh SP, 2026. Fresh produce safety – on and beyond the horizon. Woolworths Suppliers Technical Forum, Brisbane 14 May 2026.

	Gippsland, Mornington, Werribee, Richmond and Perth 2. FSANZ and Food Regulation meetings at national level. 3. State health regulators meetings in NSW, SA, WA, Tas, Qld and Vic. 4. Supermarkets (e.g. Woolworths) 5. Other meetings organised by VegNET and AUSVEG-Vic.	3. Singh SP, 2026. Fresh produce safety – on and beyond the horizon. Woolworths Suppliers Technical Forum, Melbourne 12 May 2026. 4. Singh SP, 2026. Safe leafy veg update. FSANZ Food Regulation Meeting on 20 April 2026. 5. Singh SP, 2025. Washing of Leafy Vegetables- Industry Practice in Victoria. Agriculture Victoria Biosecurity – TPP protocol meeting on 27 Nov 2025. 6. Singh SP, 2025. Safe leafy veg update. FSANZ Horticulture Standards Implementation Working Group Meeting on 19 Sep 2025. 7. Singh SP, 2025. Safe leafy veg update. Woolworths Food Safety Team Visit to Ourimbah on 16 Sep 2025. 8. Singh SP, 2025. Fresh produce safety and traceability program. International Fresh Produce Safety Conference Field Day Delegates, Ourimbah on 27 July 2025. 9. Singh SP, 2025. Safe Leafy Veg for small-scale growers. NSW Local Land Services Greater Sydney Workshop, Richmond June 2025. 10. Singh SP, 2025. Shiga toxin-producing <i>Escherichia coli</i> (STEC) contamination of leafy vegetables and risk management. FSANZ-STEC Incident Industry Roundtable meeting, Melbourne on 25 June 2025. 11. Singh SP, 2025. Safe Leafy Veg for WA Growers. The Future of Hort Science Roadshow, Perth 17 April 2025. 12. Singh SP, 2025. New insights and perspectives on fresh produce safety. Food Regulation Partnership Workshop organised by NSW Food Authority, Sydney on 7-9 April 2025. 13. Singh SP, 2025. Microbial food safety risks and their management in melons and leafy veg sectors. South Australia Department of Primary Industries and Regions, Adelaide on 18 Mar 2025 14. Singh SP, 2025. Safe Leafy veg project: industry status on microbial food safety risks. Tasmania Department of Natural Resources and Environment, Hobart on 25 Feb 2025. 15. Singh SP, 2025. Safe Leafy veg project and compliance with new food safety standards in NSW. AusVeg Biosecurity Community of Practice Meeting on 29 Jan 2025 (virtual). 16. Singh SP, 2024. Safe Leafy veg project update and food safety profile of Lockyer Valley. Workshop organised by the Lockyer Valley Growers Association, Gatton Qld on 13 Dec 2024 17. Singh SP, 2024. Safe Leafy Veg: science- and data-based food safety risk management. Organised by Agriculture Victoria on 10 Dec 2024 (virtual) 18. Singh SP, 2024. New Zealand Food Safety Science and Research Centre (NZFSSRC) Horticulture Taskforce Meeting, Wellington, NZ on 18 Nov 2024 19. Singh SP, 2024. Safe Leafy Veg- preparing towards compliance with new food safety standard. Workshop organised by VegNET at Werribee, Victoria on 20 Sep 2024
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		20. Singh SP, 2024. Safe Leafy Veg- preparing towards compliance with new food safety standard. Workshop organised by VegNET at Tyabb, Victoria on 19 Sep 2024 21. Singh SP, 2024. Safe Leafy Veg- preparing towards compliance with new food safety standard. Workshop organised by VegNET at Maffra, Victoria on 18 Sep 2024. 22. Singh SP, 2024. Mind the gap- what is next in food safety? Hort Connection 2024, Melbourne 5 June 2024 (panel discussion) 23. Singh SP, 2024. The Safe Leafy Veg project update. Vegetable Fund- Strategic Industry Advisory Panel, Hort Innovation, Melbourne on 26 March 2024. 24. Singh SP, 2024. Building capacity and resilience in the food safety systems of leafy vegetable industry. AUSVEG Biosecurity Community of Practice Meeting on 24 April 2024 (virtual) 25. Singh SP, 2024. Land-use influences microbial food safety in the horticulture sector. NSW Agricultural Land Use Planning Group meeting on 16 April 2024 (virtual) 26. Singh SP, 2023. NSW DPI's Fresh produce safety and traceability program and Safe Melons lessons. Western Growers Association on 5 Dec 2023 (virtual) 27. Singh SP, 2023. Implementation Subcommittee for Food Regulation (ISFR)- State Food and Health Regulators Meeting on 18 Sep 2023 28. Singh SP, 2023. Safe leafy veg project and preparedness towards the upcoming food safety standards. VegNET national monthly meeting on 28 July 2023 (virtual) 29. Singh SP, 2023. Are protected cropping systems invincible to microbial food safety risks? Protected Cropping Australia Conference, Brisbane, Qld 18-19 June 2023 30. Singh SP, 2023. Fresh produce safety and traceability program update. NSW Food Authority Annual Meeting, Newcastle on 2 May 2023.
Webinars	One webinar each delivered to: 1. Fresh Produce Safety Centre 2. VegNET 3. Coles Supermarkets	1. Singh SP, 2025. Safe Leafy Veg- Water Quality. Fresh Produce Safety Community of Practice Meeting on 1 October 2025. 2. Singh SP, 2025. STEC risk assessment and management organised by VegNET on 29 May 2025. 3. Singh SP, 2025. Shiga toxin-producing <i>Escherichia coli</i> (STEC) contamination of leafy vegetables and risk management. Organised by Coles Supermarkets and SAI Global 19 May 2025.
Podcast	To raise awareness of the Safe Leafy Veg project.	Singh SP, 2023. Safe leafy veg program. AUSVEG podcast recorded on 19 July 2023.
Six-monthly milestone status reports and a final report.	Milestone reports as part of the project monitoring and evaluation plan	The milestone reports (MS102, MS103, MS104, MS105 and MS106) were submitted and approved by Hort Innovation.

Outcomes

Table 3. Outcome summary

Outcome	Alignment to fund outcome, strategy and KPI	Description	Evidence
Food safety risks to consumers and industry minimised through a preventative and proactive approach	Vegetable Fund (2022-2026) OUTCOME 1: Industry supply, production and sustainability The Australian vegetable industry has increased profitability, efficiency and sustainability through innovative R&D, uptake of new technologies, sustainable BMPs and cultivars Strategy 6: Support improvements to maintain product integrity through food safety systems and processes, production and storage techniques, and correct handling procedures through the supply chain, and mitigate associated industry risks KPI: Food safety risk minimised through preventative approach	The project generated industry-specific evidence on microbial contamination risks in leafy vegetable production and processing systems and translated these findings into practical risk mitigation strategies. Through on-farm and processing surveys, environmental monitoring, grower engagement, extension activities, and development of a Best Management Practice Guide, growers and processors adopted a more proactive and preventative approach to food safety management. The project strengthened industry preparedness for emerging food safety risks and supported ongoing compliance.	National baseline survey of major food safety practices followed by growers and processors. More than three years of microbiological monitoring and risk assessment data based on 3,762 samples from the entire supply chain. Stakeholder workshops, webinars, field days and presentations. Technical resources developed and distributed to industry. Food Safety Helpdesk records and stakeholder enquiries. Industry feedback and grower participation in field trials and surveys (Appendix XIII).
Successful supply of safe leafy veg to the consumers in domestic and export markets	Outcome 1 Strategy 6: Support improvements to maintain product integrity through food safety systems and processes, production and storage techniques, and correct handling procedures through the supply chain, and mitigate associated industry risks KPI: No product recalls/food safety incidents	The project improved industry understanding of contamination pathways associated with irrigation water, organic amendments, wildlife, weather events, and processing operations. By providing evidence-based guidance and practical mitigation measures, the project supported growers and processors to strengthen preventive controls and maintain consumer confidence in leafy vegetable products. The project also provided technical support during product recalls and emerging industry issues,	No foodborne illness outbreak linked to LV reported 2023-2026. Two product recalls. Domestic baby spinach (STEC) in March 2025 Singapore: Mixed Salad recall (<i>Bacillus cereus</i>) in August 2025 Low prevalence of major pathogens identified during project monitoring. Industry adoption of risk-based management practices. Technical support provided during food safety investigations and recalls. Positive feedback from growers, processors, and

		contributing to risk management across the supply chain.	regulators regarding project outputs and support services.
Increase in grower practice change in food safety best management practices	Outcome 1 Strategy 6: Support improvements to maintain product integrity through food safety systems and processes, production and storage techniques, and correct handling procedures through the supply chain, and mitigate associated industry risks KPI: Availability of best practice food safety and safe handling information for industry to support a food safety culture	The project delivered practical, science-based information that enabled growers and processors to improve food safety practices. Grower engagement throughout the project was unprecedented, with industry participants actively supporting sampling programs, field trials, surveys, and validation studies. Findings were translated into practical recommendations through extension activities and the Best Management Practice Guide, strengthening food safety culture and capability across the industry.	Best Management Practice Guide developed. A food safety management statement template was developed in alignment with new PPP standard. 30 industry and regulatory presentations. 3 webinars and 1 podcast. Technical articles, scientific publications, and conference presentations. Evidence of grower participation in trials and monitoring activities. Food Safety Helpdesk enquiries demonstrating uptake of information and practice improvements.
Increase in collaboration between growers and researchers to ensure RD&E levy investment outputs are relevant and accessible to end-users, and industry	Outcome 1 Strategy 6: Support improvements to maintain product integrity through food safety systems and processes, production and storage techniques, and correct handling procedures through the supply chain, and mitigate associated industry risks KPI: Effective management of the issues through a coordinated response from industry	The project adopted a participatory research approach, fostering strong collaboration between growers, processors, researchers, industry bodies, retailers, and regulators. These partnerships ensured that research activities addressed real-world industry challenges and that findings were rapidly translated into practical outcomes. The Food Safety Helpdesk served as an effective mechanism for ongoing engagement, providing independent technical advice and identifying emerging risks, regulatory concerns, and future research priorities. The project also supported coordinated responses to food safety incidents and emerging industry	Participation of growers, processors, retailers, regulators, and industry organisations in project activities. Food Safety Helpdesk records documenting enquiries and follow-up support. Collaborative field trials and validation studies conducted with industry partners. Stakeholder feedback, workshops, webinars, and extension events. Industry engagement during responses to food safety incidents, environmental events, and regulatory changes.

		challenges.	
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Monitoring and evaluation

Table 4. Key Evaluation Questions

Key Evaluation Question	Project performance	Continuous improvement opportunities
To what extent has the project achieved its expected outcomes? Have all activities, KPIs and outputs been achieved? Has the project team visited leafy green growers and processors in major production and supply regions of Australia? Has the project team conducted microbiological surveillance by collecting and analysing at least 3,500 samples for target foodborne bacterial pathogens and mapped the food safety risks along the supply chain? Has the project team engaged with the leafy green growers and processors by providing them food safety monitoring reports and technical advice as and when needed? Has the project team provided the food safety helpdesk service and site visits to the growers, packers and other stakeholders?	The project successfully achieved all major activities, outputs and KPIs outlined in the project plan. The project team conducted extensive engagement with LV growers (154) and processors (40) across major production regions of Australia. 3,762 samples were collected and analysed for key foodborne pathogens, generating one of the most comprehensive datasets on microbial food safety risks in the Australian leafy vegetable supply chain. Food safety risks were identified, characterised and communicated to industry through reports, technical advice, presentations and a Best Management Practice Guide. The Food Safety Helpdesk and site visits provided ongoing support to growers, processors and other stakeholders. The project strengthened industry capability to identify, assess and manage microbial food safety risks using a preventative and proactive approach.	Future projects could expand surveillance to additional commodities and emerging hazards, including antimicrobial resistance and environmental contaminants. Greater integration of digital monitoring tools, predictive analytics and real-time risk assessment systems could further strengthen industry preparedness and response capabilities. Long-term monitoring programs would help measure sustained practice change and industry impact. The first three Ws (water, waste from animals and weather events) of the ‘Mind the W’ Framework present the greatest challenges for risk management and compliance with the new food safety standards. Considering both risk magnitude and factors beyond growers’ direct control, the project identified three highest-priority domains requiring focused attention: irrigation and postharvest water, soil organic amendments, and extreme weather events.
How relevant was the project to the needs of intended beneficiaries? Did target beneficiaries participate in the project and had access to technical information and advice as proposed?	Yes. Target beneficiaries participated extensively throughout the project and engagement exceeded original expectations. A total of 154 leafy vegetable growers and 40 processors/packing facilities participated in project activities across all major leafy vegetable production regions of Australia. Growers and processors were actively involved in microbiological surveillance activities, including access to farms, water sources, soils, production environments, processing facilities and finished products for	Future research could focus on emerging regulatory requirements, climate change impacts on food safety risks, innovative water treatment technologies, and cost-effective risk mitigation strategies suitable for diverse production systems. Additional work may also be required to better understand contamination pathways associated with wildlife, environmental reservoirs and extreme weather events.

To what extent has the project met the needs of Australian leafy veg industry? Are there any gaps or additional opportunities for research?	sampling and analysis. Many participants remained engaged throughout the project period, contributing to repeated sampling events, field investigations, technical discussions and validation activities. Participants received individual monitoring reports, technical advice, risk assessments, site visits and ongoing support through the Helpdesk. This participatory approach ensured beneficiaries had direct access to project findings and practical guidance for managing food safety risks within their operations. The project strongly met the needs of the Australian leafy vegetable industry by addressing key microbial food safety risks and providing practical, evidence-based solutions to growers and processors. In addition to generating valuable data on contamination risks across the supply chain, the project supported the industry's transition to the Primary Production and Processing (PPP) Standards by providing timely technical advice, compliance guidance and support. Ongoing engagement and liaison with regulators across all states helped ensure consistent interpretation of regulatory requirements and effective management of emerging food safety issues. While the project significantly advanced understanding of microbial food safety risks in LV, several opportunities remain for future research and development listed in the "Recommendations" section.	
How well have intended beneficiaries been engaged in the project? Has the project team engaged with proposed number of growers/packers and other stakeholders? Has the project team communicated the food safety best practice to the	A total of 154 leafy vegetable growers and 40 processors/packing facilities participated in project activities across all major leafy vegetable production regions of Australia. Beneficiary engagement exceeded expectations and represented one of the project's major strengths.	Future projects could establish formal grower reference groups and regional demonstration sites to further strengthen co-design and adoption of research outcomes. Additional engagement with smaller enterprises and emerging industry sectors may also increase project reach and impact.

end-users?	Growers and processors demonstrated an unprecedented level of participation through sample collection, farm access, field trials, surveys and technical discussions over the three-year project period. The project team maintained regular communication through individual reports, presentations, workshops, webinars, industry publications and direct technical support. The participatory research approach ensured that project activities remained relevant and responsive to industry needs.	
To what extent were engagement processes appropriate to the target audience/s of the project? Did the project engage with industry levy payers through appropriate methods? How appropriate were the project activities and outputs for achieving its intended outcomes? How appropriate were the management and governance processes and the resources used for delivering the project?	The engagement methods were highly appropriate for industry-levy payers and other stakeholders. A combination of site visits, workshops, webinars, presentations, technical publications, one-on-one consultations and the Food Safety Helpdesk ensured information was delivered through channels preferred by industry. Project governance and management processes were effective, enabling strong collaboration between researchers, growers, processors, retailers, industry organisations and regulators. Resources were used efficiently to maximise stakeholder engagement and knowledge transfer.	Future projects could further utilise digital communication platforms, online training modules and interactive decision-support tools to increase accessibility and broaden stakeholder participation. Enhanced mechanisms for measuring adoption and behaviour change may also strengthen evaluation of engagement outcomes
What efforts did the project make to improve efficiency? Did the project identify opportunities to improve efficiencies? (including implementation of new technology, technique, practices, workflow etc.)	The project improved efficiency through a highly collaborative and industry-led approach to sampling, surveillance and stakeholder engagement. Rather than relying solely on project staff, growers and processors made substantial in-kind contributions through their Quality Assurance teams, who collected, and submitted microbiological samples over extended periods, in some cases for up to two years. This approach enabled large-scale national surveillance to be undertaken in a cost-effective manner while maintaining strong industry ownership of the project. The project also leveraged in-kind resources from NSW DPIRD, regional	Future opportunities include greater adoption of automated environmental monitoring systems, predictive modelling, genomic technologies and data-sharing platforms to improve efficiency of surveillance, risk assessment and incident response. Strengthening integration between industry monitoring programs and research activities may further enhance return on investment from levy-funded projects.

	grower bodies and industry organisations to support grower engagement, sample collection, site visits, extension activities and communication across major production regions. All industry events were organised in collaboration with VegNET and other regional bodies to maximise project resource use efficiency.	
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Recommendations

For growers and processors

- Adopt the Best Management Practice (BMP) guidance developed through the project to strengthen food safety risk management and provide feedback to the NSW DPIRD for further improvements.
- Implement risk-based monitoring of key pre-harvest and postharvest inputs, particularly irrigation water, organic amendments, harvest operations and wash water systems.
- Continue to develop a proactive food safety culture through staff training, verification activities and routine environmental monitoring.
- Use project findings and FSMS template to support compliance with PPP Standards and customer food safety requirements.
- Maintain preparedness for extreme weather events, flooding and other environmental factors that may increase microbial contamination risks.
- Adopt an area-wide food safety management approach rather than focusing solely on individual farm operations, recognising that microbial contamination risks often originate and spread beyond farm boundaries.

For Hort Innovation and industry

- Continue investment in national food safety surveillance programs to monitor emerging microbial hazards and provide evidence-based support for industry and regulators.
- Maintain or expand the Food Safety Helpdesk model as an effective mechanism for confidential technical support, rapid response to emerging issues and identification of future RD&E priorities.
- Support ongoing extension and communication activities to maximise adoption of project findings
- Facilitate industry-wide access to practical decision-support tools, training resources and food safety guidance materials developed through the project.

Development and adoption activities

- Deliver targeted extension programs, field demonstrations, webinars and training workshops to support implementation of project recommendations.
- Integrate project findings into existing industry assurance schemes, training programs and food safety certification systems.
- Strengthen collaboration between growers, processors, retailers, researchers and regulators to ensure continued sharing of knowledge and rapid response to emerging food safety issues.
- Encourage industry participation in future monitoring and research programs, building on the strong collaborative networks established through this project.

Future RD&E priorities and next steps

Building on the strong industry engagement, national surveillance dataset and risk assessments generated through this project, future RD&E investment should focus on addressing key knowledge gaps and developing practical solutions that further strengthen microbial food safety management in the Australian vegetable industry.

1. Develop and evaluate practical, scalable and cost-effective interventions for irrigation and postharvest water management under commercial production conditions.
2. Generate field-relevant data on soil organic amendments and associated microbial risks in LV production.
3. Investigate the impact of extreme weather events and regional land-use patterns on microbial food safety risks.
4. Design and implement a high-throughput, data-driven food safety surveillance and early-warning system for the

- LV supply chain.
5. Develop advanced technical resources and maintain an independent Food Safety Helpdesk service to support growers, packers and supply chain stakeholders.

Refereed scientific publications

Journal articles

1. Rood L, Kocharunchitt C, Bowman C, Stanley R, Ross T, Danyluk M, Warriner K, Singh SP, Eyles A (2025). Potential for in-field pre-harvest control of foodborne human pathogens in leafy vegetables: identification of research gaps and opportunities. *Trends in Food Science and Technology*, 158, 104928.
2. Singh SP (2023) Flooding adversely affects fresh produce safety. *Microbiology Australia* 44, 185-189.
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Intellectual property

No commercialisable project IP or commercialisation to report.

Acknowledgements

The project team sincerely thanks the LV growers and processors across Australia whose trust, openness and practical insights were fundamental to the success of the project and the generation of industry-relevant outcomes. The project acknowledges the invaluable support provided by industry organisations and stakeholder groups, including AUSVEG, AUSVEG Vic, Vegetables WA, the Lockyer Valley Growers Association, Protected Cropping Australia, Australian Organic Limited and many others. Regional engagement was strengthened through the support of Regional Development Officers (RDOs) from the VegNET program, whose efforts facilitated grower participation and knowledge exchange across major vegetable-growing regions. Special thanks are extended to Professor Mark Turner and his team at the University of Queensland for collaboration. The project team also acknowledges Food Standards Australia New Zealand (FSANZ), food regulators, supermarkets, and supply chain stakeholders for their constructive engagement. We thank the many individuals, organisations, researchers, extension officers, and facilitators who contributed to sample collection, field activities, stakeholder engagement, and project delivery across diverse locations throughout Australia.

Appendices

- I. Microbial risk mapping (Confidential)
- II. Industry practice review
- III. Whole-genome sequencing data (Confidential)
- IV. Microbiome analysis of leafy greens
- V. Best practice guidance
- VI. Journal article (Rood et al., 2025)

- VII. Journal article (Singh 2023)
- VIII. Technical article – NSW PrimeFact (Singh SP, 2023). Microbial food safety risks and bushfires
- IX. Technical article – NSW PrimeFact (Singh SP, 2025). STEC Risk management in leafy veg
- X. Technical article – AUSVEG (Singh 2025) Safe Leafy Veg – Interim Recommendations
- XI. Technical article – Mind the W Framework (Singh et al., 2026)
- XII. Technical article – Safe Leafy Veg (Singh et al., 2026)
- XIII. Grower feedback article snippet
- XIV. Food safety management statement (FSMS) template

APPENDIX II

Project activity 2

Evaluate and monitor industry food safety practices and identify the potential hotspots for managing microbial contamination and cross-contamination during production and postharvest handling.

Summary- Industry practice review

The industry practice review provided a comprehensive national snapshot of microbial food safety management practices within the LV industry. The project engaged 154 growers and 40 processing facilities representing diverse crop types, farming scales, production systems, and geographic regions across Australia. The findings demonstrated that leafy vegetable production in Australia is highly dependent on field-based systems and surface water irrigation, with most growers using overhead sprinkler irrigation methods that directly expose edible plant surfaces to irrigation water. While the majority of growers undertook microbiological testing of irrigation water, relatively few applied active water treatment interventions, highlighting irrigation water management as one of the most critical food safety risk areas within the industry.

Seasonal deterioration in surface water quality, particularly during summer periods and following heavy rainfall or flooding events, further reinforced the vulnerability of irrigation water systems to environmental contamination. Encouragingly, several growers implemented practical water quality improvement strategies, including sediment settling ponds, filtration systems, dam lining, aeration, fencing, and wildlife exclusion measures, which substantially improved irrigation water quality outcomes.

Summary- Industry practice review

The review also identified important trends relating to organic soil amendment use, environmental risk exposure, postharvest processing practices, and adoption of formal food safety systems. Approximately half of the growers used organic amendments containing animal waste, although treated composts were more commonly used than untreated manures. Notably, the use of untreated organic amendments was predominantly associated with smaller farming operations, indicating potential resource and technical capability limitations within small-scale enterprises. Environmental vulnerabilities including flooding, livestock proximity, wildlife intrusion, and dust storms were commonly reported; however, implementation of mitigation measures varied considerably across growers and risk categories.

Within postharvest operations, cooling and wash water sanitisation practices were widely adopted, particularly in baby leaf processing systems, demonstrating strong industry awareness of postharvest quality and microbial risk management. However, relatively few processors implemented structured environmental monitoring programs despite the recognised importance of processing environments as reservoirs for persistent pathogens such as *Listeria monocytogenes*.

Adoption of GFSI-certified food safety schemes was strongly associated with farm scale, with all large-scale growers certified compared with very low uptake among small and medium enterprises. Overall, the industry practice review highlighted that while the Australian leafy vegetable industry has demonstrated significant progress in food safety awareness and risk management, important opportunities remain to strengthen irrigation water management, environmental monitoring, organic amendment practices, and practical support for growers to improve risk management and compliance with standards.

Leafy vegetable farm operations characteristics

Crops	Number of growers (n = 154)
Baby leaf (baby spinach and mixed leaf)	19 (12.3%)
Leafy heads (Lettuce heads and cabbage)	45 (29.2%)
Baby leaf and leafy heads	41 (26.6%)
Others (Herbs, Asian vegetables, spring onions, kale etc)	49 (31.8%)
State	Number of growers (n =154)
Victoria	38 (24.7%)
New South Wales	35 (22.7%)
Queensland	30 (19.5%)
Western Australia	25 (16.2%)
South Australia	16 (10.4%)
Tasmania	6 (0.04%)
Northern Territory	4 (0.03%)
Scale of operation	Number of growers (n =154)
Large (>10 hectares)	65 (42.2%)
Medium (2-10 hectares)	32 (20.8%)
Small (<2 hectares)	57 (37%)
GFSI-certified food safety scheme	Number of growers (n =154)
Yes	94 (61%)
No	-
Unsure	60 (39%)
Adoption of food safety schemes by farming scale	Number of growers (n =154)
Large (>10 hectares)	65 out of 65 (100%)
Medium (2-10 hectares)	6 out of 32 (12.4%)
Small (<2 hectares)	3 out of 57 (5.3%)
Production system	Number of growers (n =154)
Conventional	143 (92.9%)
Organic	11 (0.07%)
Production method	Number of growers (n =154)
Field production	115 (74.7%)
Hydroponic	39 (25.3%)

Key industry practice information on inputs (water and soil) for field production (n=115) of leafy vegetables

Preharvest water source	Number of growers (n = 115)
Surface water (river, farm pond, creeks and rainwater)	87 (75.6%)
Ground water	8 (0.07%)
Surface and ground water	20 (17.4%)
Preharvest water treatment	Number of growers (n = 115)
Yes (mainly filtration)	15 (13.1%)
No	100 (86.9%)
Irrigation method	Number of growers (n = 115)
Overhead sprinklers	110 (95.7%)
Overhead and drip	5 (4.3%)
Preharvest water testing (microbiological)	Number of growers (n = 115)
Yes	101 (87.8%)
No	14 (12.2%)
Organic soil amendment with animal waste	Number of growers (n = 115)
Yes	58 (50.4%)
No	57 (49.6%)
Organic amendment treatment	Number of growers (n = 58)
Treated (Compost)	33 (56.8%)
Untreated (poultry litter and cattle manure)	14 (24.1%)
Mixture of treated and untreated	11 (18.9%)
Organic amendment application	Number of growers (n = 58)
Pre-planting (soil incorporation)	53 (91.4%)
Pre- and post-planting (side/top dressing)	5 (8.62%)
Untreated organic amendment <u>use</u> by farming scale	Number of growers (n = 14)
Large (>10 hectares)	1 (7.1%)
Medium (2-10 hectares)	1 (7.1%)
Small (<2 hectares)	12 (85.7%)

Water quality management

- Storage in farm ponds
- Coarse filtration and frequent backflushing

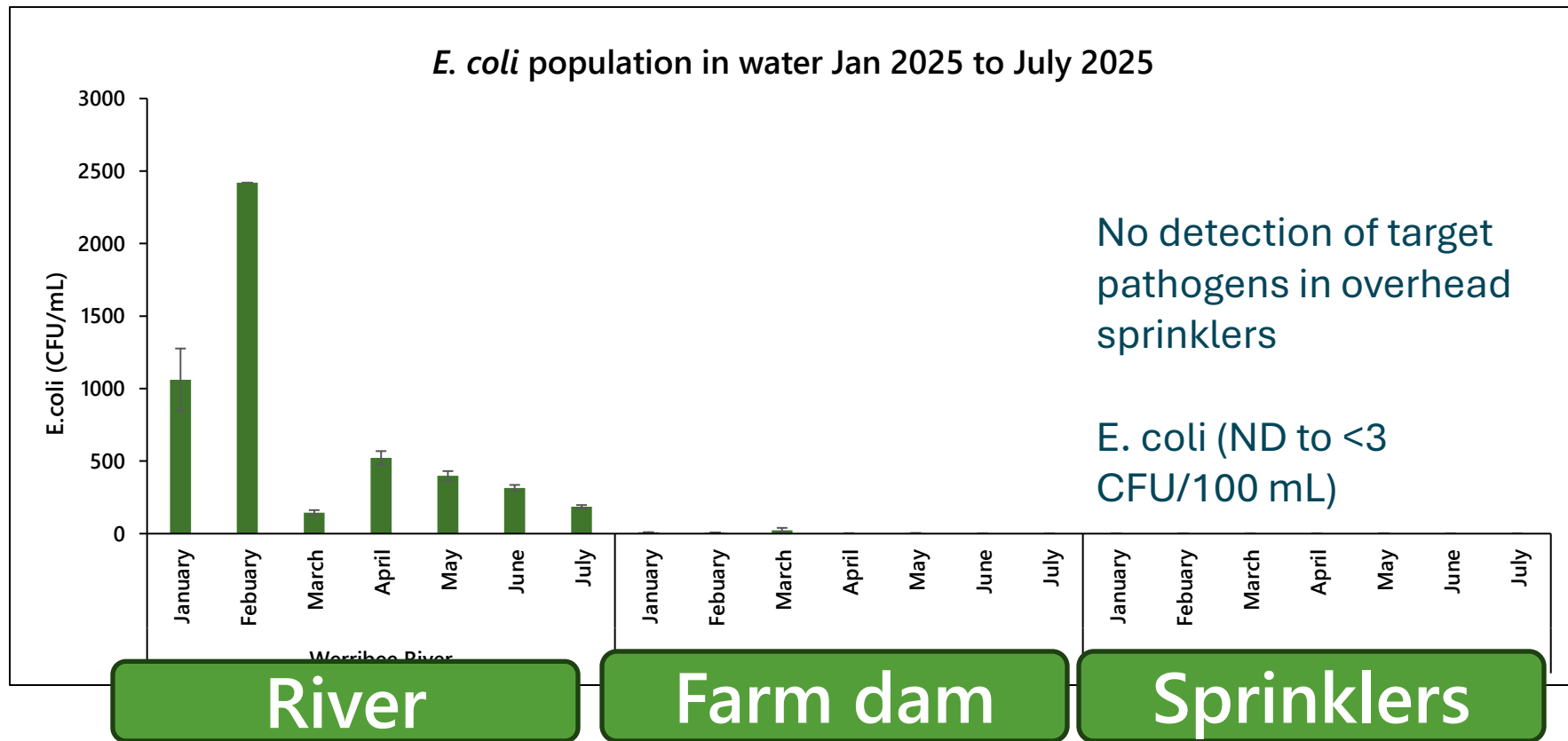


Pumping from
river



Sediment control and coarse filtration
(before and after storage in farm pond)

What does good look like on a farm?



Practical considerations

- **Neighbour's land-use and upstream contamination of surface water sources are beyond growers' control.**
- Capital costs- developing a farm pond and installing coarse filtration/water treatment
- No cost-effective commercial solution for disinfection of large irrigation water volumes
- Growers can't withhold overhead irrigation for two days prior to harvesting of leafy veg

Water: risk assessment and management

Seasonal variation in surface water quality is high, summer months and heavy rainfall events are worst scenarios

Best practice recommendations

- Assess upstream water contamination risks
- Water storage in ponds/dams for sediment management
- Coarse filtration and frequent backflushing
- Monthly water sampling and testing for generic E. coli count for year-around leafy production
- Evaluate historical data trends

Farm location vulnerabilities to livestock operations, extreme weather and wildlife pressure for field production (n=115)

Farm location vulnerabilities	Number of growers (n = 115)	Effective risk mitigation measures	Number of growers
Flooding and heavy run-off exposure ^a	35 (30.4%)	Drainage, levees, dykes, raised beds etc	4 out of 35 (11.4%)
Proximity to livestock (within 1 km) ^b	16 (13.9%)	Fencing and windbreaks	13 out of 16 (91.3%)
Flooding and proximity to livestock ^{a+b}	10 (8.9%)	Fencing, drainage, levees, raised beds, windbreaks etc	1 out of 10 (10%)
Wildlife intrusion risk ^c	18 (15.7%)	Fencing and windbreaks	0 out of 18 (0%)
Wildlife and animal intrusion ^{b+c}	34 (29.6%)	Fencing and windbreaks	13 out of 34 (26.5%)
Dust storms	11 (9.6%)	Perennial and annual windbreaks	1 out of 11 (9.1%)
Bushfires (indirect wildlife impact)	9 (7.8%)	Fencing and windbreaks	0 out of 9 (0.0%)

Processing operations characteristics for leafy vegetables (n=40)

Crops processed	Number of processors (n = 40)
Baby leaf (baby spinach and mixed leaf)	10 (25%)
Leafy heads (Lettuce heads and cabbage)	9 (22.5%)
Baby leaf and leafy heads	17 (37.5%)
Others (Herbs, Asian vegetables, spring onions, kale etc)	4 (31.8%)
State	Number of processors (n = 40)
Victoria	19 (47.5%)
Queensland	8 (20%)
Western Australia	6 (15%)
South Australia	3 (7.5%)
Tasmania	3 (7.5%)
New South Wales	1 (2.5%)
Northern Territory	-
Postharvest cooling	Number of processors (n = 40)
Yes	38 (95%)
No	2 (5%)
Postharvest cooling method	Number of processors (n = 38)
Vacuum cooling	29 (72.5%)
Air cooling	9 (23.5%)
Postharvest washing and sanitisation	Number of processors (n = 21)
Yes (baby leaf and others including herbs)	21 (52.5%)
Wash water sanitiser use	19 out of 21 (90.5%)
Sanitiser type- peroxyacetic acid (PAA)	12 out of 19 (63.2%)
Sanitiser type- chlorine	7 out of 19 (36.7%)
Environmental monitoring and management	Number of processors (n = 40)
Regular monitoring and management	9 out of 40 (22.5%)

Postharvest water



Postharvest Washing and Sanitisation



Produce Washing



- Remove soil and debris
- Remove nutrient-rich exudates from cut ends
- Cooling and shelf-life

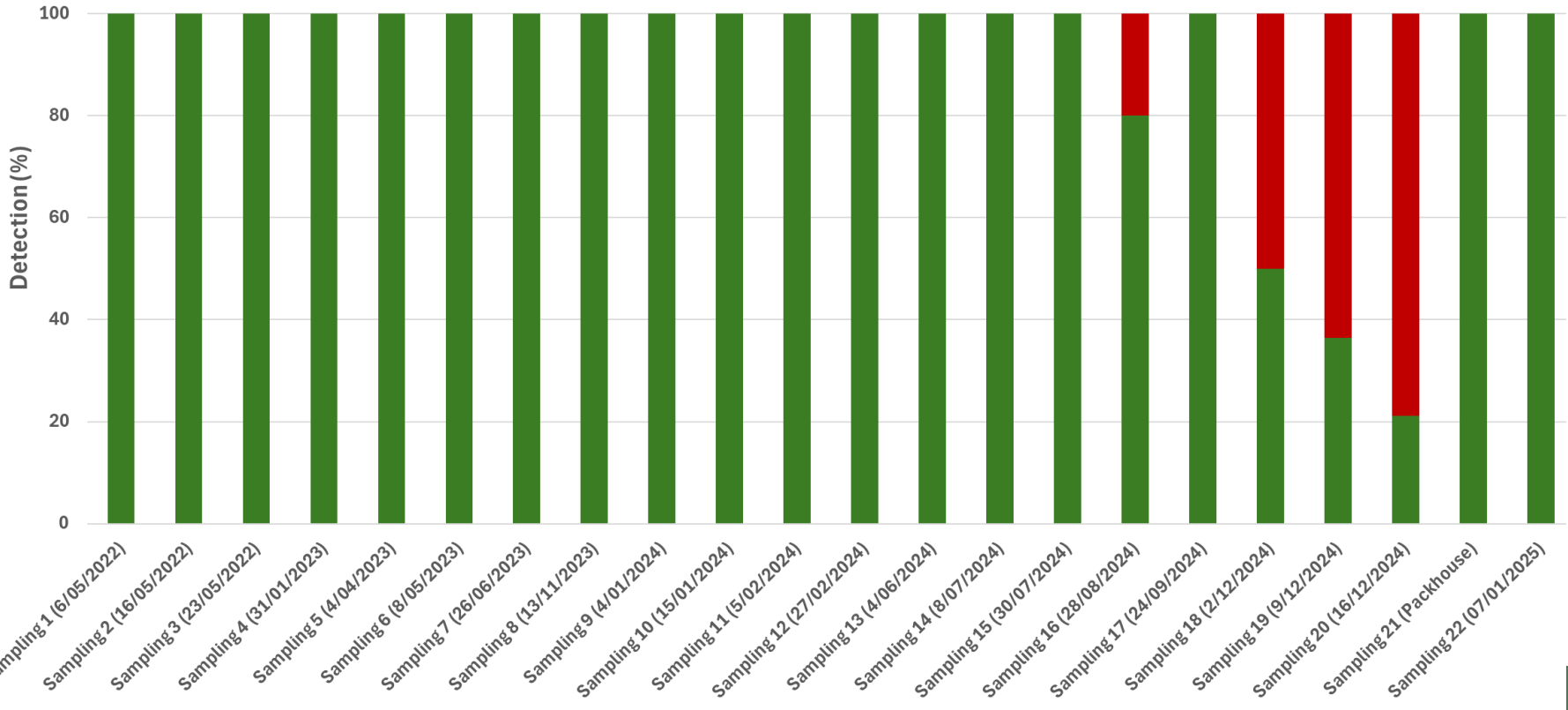
Produce Sanitisation



- Reduce microbial load on produce
- Surface sanitisation

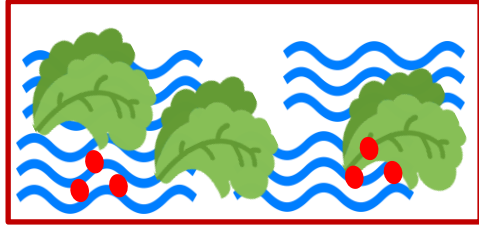
Postharvest water: cross-contamination

■ Negative detections ■ Positive Detections



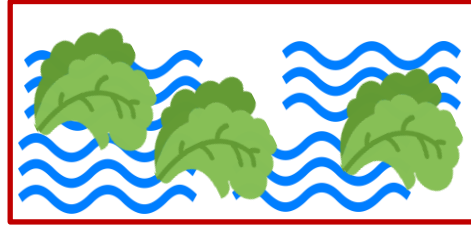
Cross-contamination scenario (real one)

TANK 1



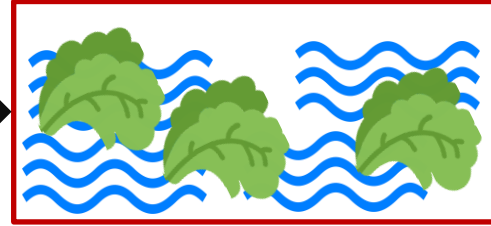
- *E. coli*- too numerous to count
- Pathogenic *E. coli* and *Listeria innocua*
- Chlorine 0.2 ppm

TANK 2



- *E. coli*- not detected
- Pathogens- not detected
- Chlorine 19.0 ppm

TANK 3



- *E. coli*- not detected
- Pathogens- not detected
- Chlorine 22.0 ppm



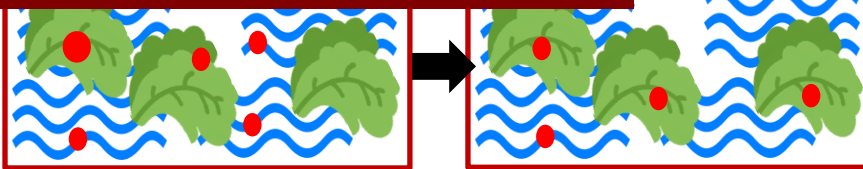
- *E. coli*- not detected
- Pathogens- not detected
- PAA 70.0 ppm

- *E. coli*- not detected
- Pathogens- not detected
- PAA 55.0 ppm

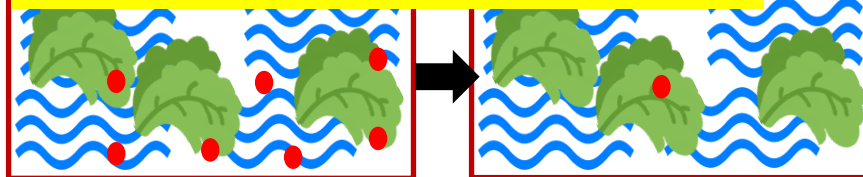
- *E. coli*- not detected
- Pathogens- not detected
- PAA 37.0 ppm

Cross-contamination scenarios

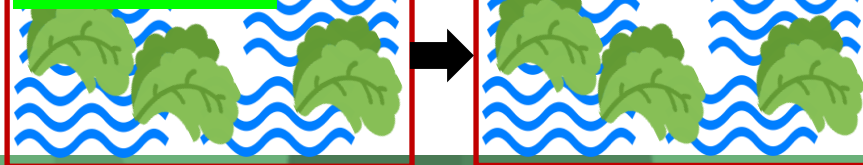
Inadequate sanitiser concentration in all tanks/flumes and contact time



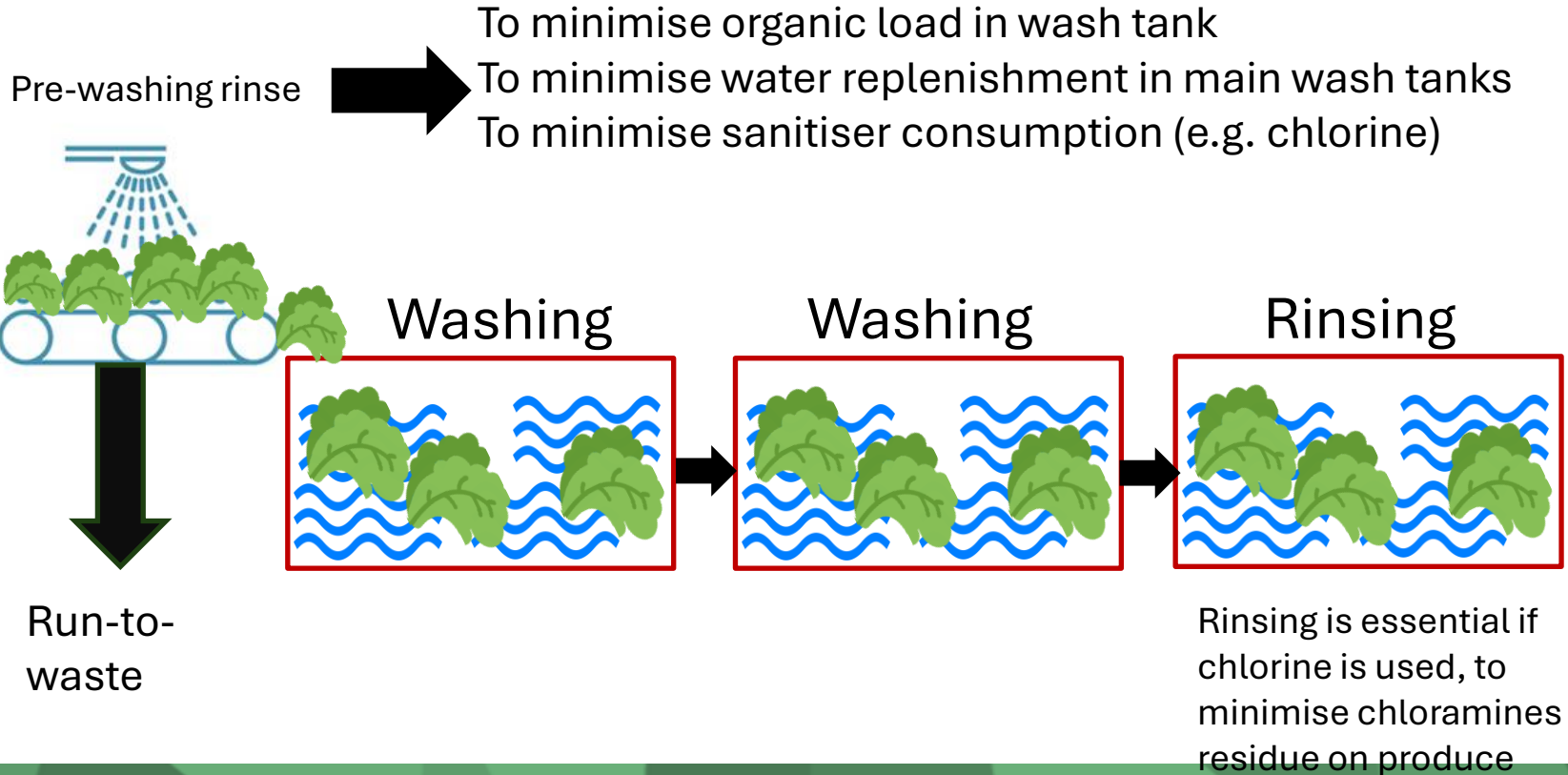
Inadequate sanitiser concentration in a wash tank or flume and contact time



Adequate sanitiser concentration and contact time



Best practice- washing and sanitisation





Safe 
Leafy Veg



THE UNIVERSITY
OF QUEENSLAND
AUSTRALIA

CREATE CHANGE

Hort
Innovation

**VEGETABLE
FUND**

APPENDIX IV

Project activity 3
Microbiome analysis of leafy vegetables

Summary- Microbiome Analysis

Microbiome analysis demonstrated that washing cycle (double or triple) significantly influenced microbial load on leafy vegetables. Triple washing was consistently more effective than double washing for both spinach and rocket, resulting in lower increases in total plate counts during one week of refrigerated storage.

As peroxyacetic acid (PAA) concentrations remained above recommended sanitisation thresholds throughout the washing process, the improved microbial outcomes associated with triple washing are likely attributable to enhanced physical removal of microorganisms rather than differences in sanitiser concentration. These findings indicate that the number of washing cycles is a critical operational parameter influencing washing efficacy and subsequent product shelf life.

Substantial differences in microbial community composition were observed between crop types and production systems. Spinach exhibited greater genus-level diversity than rocket, suggesting a more complex and heterogeneous phyllosphere microbiome. In contrast, rocket microbiomes were frequently characterised by low diversity and dominance of one or two bacterial genera, particularly under organic production systems.

Organically grown spinach and rocket were associated with a higher relative abundance of Firmicutes, with *Exiguobacterium_A* and *Bacillus_A* representing dominant taxa, respectively. Conversely, conventionally produced samples were predominantly colonised by Proteobacteria, particularly *Pseudomonas_E*.

Prior to washing, organic spinach showed elevated levels of *Exiguobacterium_A*, whereas organic rocket was consistently dominated by *Bacillus_A*. Conventional spinach and rocket samples were frequently dominated by *Pseudomonas spp.*, especially following washing and subsequent cold storage.

Summary- Microbiome Analysis

Peroxyacetic acid washing resulted in an immediate reduction in total bacterial abundance; however, its effects on microbial community composition were selective rather than uniform. Washing substantially reduced the relative abundance of *Exiguobacterium_A*, particularly in organic spinach and conventional rocket. In contrast, *Pseudomonas_E* demonstrated considerable tolerance to the washing process and, in several instances, increased in relative abundance following successive wash cycles, most notably in conventional spinach.

Bacillus_A increased markedly in relative abundance after washing in both organic and conventional rocket. This response likely reflects the inherent resistance of *Bacillus* species to chemical sanitisation, including the persistence of spores and stress-tolerant vegetative cells. These findings suggest that while PAA-based washing effectively reduces overall microbial loads, its capacity to control *Bacillus* may be limited, even at concentrations exceeding 100 ppm.

The results support the adoption of triple washing as a preferred commercial practice for spinach and rocket processing, while highlighting the need for alternative or complementary interventions to improve control of resilient bacterial populations and optimise microbial quality outcomes.

Introduction

The microbiome present on leafy vegetable surfaces, often referred to as the phyllosphere microbiome, is increasingly recognised as a critical component of fresh produce quality, shelf life, and food safety. Leaf surfaces harbour complex and dynamic microbial communities comprising bacteria, fungi, and yeasts that interact with each other and with the host plant. Importantly, the composition and diversity of the phyllosphere microbiome can also affect the establishment, survival, and persistence of human enteric pathogens such as *Salmonella* and *Listeria monocytogenes*. A diverse and stable microbial community may provide colonisation resistance by competing for nutrients and attachment sites or by producing antimicrobial metabolites, whereas disturbed or simplified microbiomes may create ecological niches that favour pathogen persistence and proliferation.

The composition of leafy vegetable microbiomes is strongly influenced by preharvest factors, including crop species, cultivar, climate, soil characteristics, irrigation water quality, fertilisation practices, organic amendments, wildlife activity, and farming systems. Organic and conventional production systems often support distinct microbial communities due to differences in nutrient inputs, soil management practices, and agrochemical use. Environmental reservoirs such as soil, irrigation water, livestock, and wildlife contribute microorganisms that colonise leaf surfaces and shape microbiome structure throughout crop growth. Seasonal conditions, temperature, rainfall events, and irrigation practices further influence microbial succession and diversity. Consequently, the preharvest environment plays a fundamental role in determining both the overall microbial ecology of leafy vegetables and the potential introduction of foodborne pathogens into production systems.

Introduction

Following harvest, postharvest handling and processing practices can substantially modify the phyllosphere microbiome. Washing, sanitisation, cooling, packaging, and storage selectively remove or suppress certain microbial populations while allowing others to survive and become dominant. Sanitising agents such as chlorine and peroxyacetic acid (PAA) often reduce total microbial loads but may have differential effects on individual taxa, resulting in shifts in community composition rather than uniform microbial reduction. Microorganisms possessing enhanced stress tolerance, biofilm-forming capacity, or spore-forming ability may persist throughout processing and become enriched during storage. Such shifts can influence product shelf life, spoilage potential, and pathogen ecology.

Understanding how preharvest and postharvest factors shape microbial communities is therefore essential for developing microbiome-informed food safety strategies. Advances in microbiome analysis provide opportunities to identify microbial indicators of contamination risk, understand pathogen interactions within complex microbial ecosystems, and develop targeted interventions that promote beneficial microflora while reducing the survival and transmission of foodborne pathogens in fresh produce supply chains.

Objectives

- To determine efficacy of washing and sanitisation of spinach and rocket leaves under commercial conditions
- To determine microflora on spinach and rocket leaves as influenced by
 - Production system (organic versus conventional system)
 - Leaf type (spinach versus rocket)
 - Washing and sanitisation (triple versus double)
 - Storage (fresh and after 7 days)

Methodology

Organic and conventional produce samples were collected before washing and after washing.

Samples were collected by QA team of a commercial processing facility in Melbourne and transported to the UQ laboratory in Brisbane under chilled conditions.

Upon receipt samples were analysed for Day 2 (initial) and then stored in a refrigerator ($<5^{\circ}\text{C}$) for one week and data collected on Day 9.

Observations:

- Total plate count (Log CFU/g)
- Microflora analysis (whole genome sequencing approach)

Sample collection from processing operation

Samples	Sample code (Day 2)	Treatment	PAA (ppm)	Sample code (Day 9)
Organic spinach (F farm)	S1	Before wash	Tank 1: 110	S13
	S2	After first wash	Tank 2: 150	S14
	S3	After wash	Tank 3: 80	S15
Organic rocket (F farm)	S4	Before wash	Tank 1: 190	S16
	S5	After first wash	Tank 2: 150	S17
	S6	After wash		S18
Conventional spinach (W farm)	S7	Before wash	Tank1: 160	S19
	S8	After first wash	Tank 2: 130	S20
	S9	After wash		S21
Conventional rocket (T farm)	S10	Before wash	Tank 1: 180	S22
	S11	After first wash	Tank 2: 190	S23
	S12	After wash	Tank 3: 40	S24

Methodology

Microbiome analysis

For microbiome analysis, 20 g of leaves from each sample were aseptically weighed and transferred into 200 mL sterile containers, after which 50 mL of sterile NaCl solution was added. Samples were vigorously shaken by hand for 3 minutes to ensure thorough contact between all leaf surfaces and the extraction solution. The resulting wash solution was transferred into 50 mL centrifuge tubes and centrifuged with 4000 x g at 4 °C for 20 min. The resulting pellets were collected and stored at -20 °C until DNA extraction.

Microbial DNA was extracted using the DNeasy PowerSoil Pro Kit (Qiagen, Germany) according to the manufacturer's instructions. DNA concentration and purity were assessed using a NanoDrop spectrophotometer. Samples with DNA concentrations exceeding 5 ng μL^{-1} were submitted for amplicon sequencing targeting the 16S rRNA gene (bacterial communities) using PacBio sequencing technology at the Australian Genome Research Facility (AGRF), Brisbane, Australia.

An additional set of samples was processed following one week of refrigerated storage under normal atmospheric conditions at 4 °C to assess changes in microbial community composition during storage.

Methodology

Microbiome analysis

PacBio HiFi full-length 16S rRNA gene reads were processed in QIIME2. Reads were quality filtered and denoised using the DADA2 plugin to generate amplicon sequence variants (ASVs). Taxonomic assignment of ASVs was performed using two complementary approaches. First, a consensus alignment-based classification was conducted using VSEARCH against the Genome Taxonomy Database (GTDB; release r207) to provide a highly consistent taxonomy framework. Second, ASVs were classified using a naïve Bayes machine-learning approach implemented within the DADA2/QIIME2 workflow. For this machine-learning classification, a tiered database strategy was applied such that assignments were attempted against GTDB (r207) first, and if no species-level match was obtained, the workflow successively fell back to the SILVA rRNA database (v138), and then to the NCBI RefSeq 16S rRNA database supplemented with the Ribosomal Database Project (RDP). Outputs from these classification strategies were used to generate the final ASV feature table and taxonomic profiles for downstream microbiome analyses (AGRF, Australia).

Results

Total plate count

The initial total plate count (TPC) of samples prior to washing exceeded 6 log CFU/g for all samples, with the exception of organic rocket, which showed a lower initial load of approximately 5 log CFU/g. Following washing, organic spinach exhibited a reduction of approximately 1 log CFU/g after the first wash, with a further reduction of about 0.5 log CFU/g after the second wash. In contrast, the remaining samples showed an initial reduction of around 1 log CFU/g after the first wash, with no additional reduction observed after the second wash (Fig. 4.1).

During one week of refrigerated storage, the unwashed conventional spinach sample exhibited an increase of more than 1 log CFU/g, whereas the corresponding washed sample increased by only approximately 0.5 log CFU/g. In comparison, conventional rocket samples showed little change in TPC over the storage period. Conversely, organic samples displayed a notable increase in microbial load, with TPC rising by nearly 1 log CFU/g after one week of storage, both before and after washing. A similar trend was observed for organic rocket, whereas conventional rocket did not exhibit a substantial increase in TPC during refrigerated storage (Fig. 4.1)

Cell counts of different samples and treatment in spinach and rocket

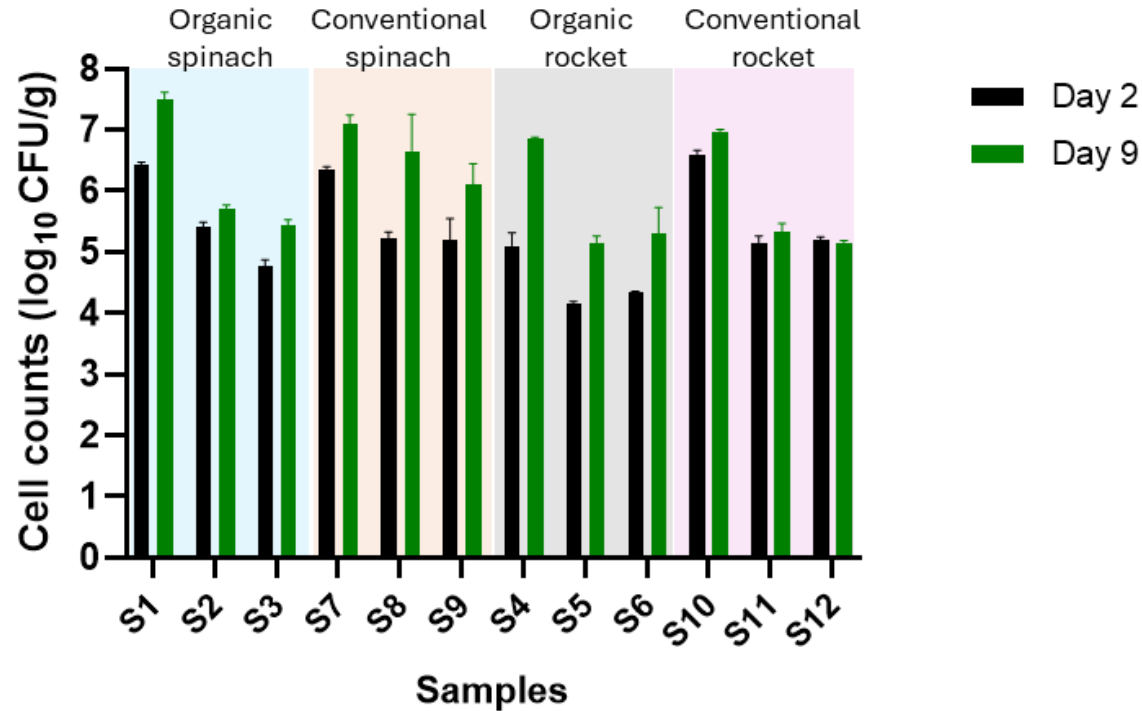


Figure 4.1. Cell counts of different samples and treatment in spinach and rocket. For each type of leaf, the order from left to right: Before wash, first wash and second wash.

Spinach: Washing and sanitisation efficacy

Plate counts on organic and conventional spinach were similar before undergoing washing process.

Organic spinach

- Triple wash led to approximately two-log reduction in the total count.

First wash reduced plate count by almost one log, and the subsequent two wash tanks further reduced the count by another one log.

Half a log increase in total count occurred during one-week cold storage.

Conventional spinach

- Double wash led to approximately one-log reduction in the total count.

Approximately one log increase in total count occurred during one-week cold storage.

Rocket: Washing and sanitisation efficacy

Plate counts on conventional rocket were higher than organic before undergoing washing process.

Organic rocket

- Double wash led to approximately one-log reduction in the total count.
One-log increase in total count occurred during one-week cold storage.

Conventional rocket

- Triple wash led to approximately two-log reduction in the total count.
Minor increase (<0.5 log) in total count occurred during one-week cold storage.

Results: Washing efficacy

Triple washing was more effective than double washing, regardless of leaf type (spinach and rocket).

Triple washed products showed lower increase in total plate count compared to the double washed products during one-week cold storage.

Since PAA concentrations remained above the recommended limits for water sanitisation, the number of washes remains the key parameter affecting washing and sanitisation efficacy.

Results: Microbiome

Bacterial microbiome using 16s RNA: Diversity of microbial community at phylum level

Overall, the bacterial communities associated with spinach and rocket were dominated by Proteobacteria and Firmicutes, with Actinobacteriota present at lower relative abundance across most samples. The relative contribution of these major phyla varied depending on the production method (organic versus conventional).

In spinach samples, Proteobacteria accounted for approximately 50% of the total community in organically produced samples, whereas their relative abundance increased to around 80% in conventionally produced spinach. A similar trend was observed in rocket samples. Most organic rocket samples contained around 20 - 30% Proteobacteria, while conventionally produced rocket showed substantially higher proportions, often reaching around 50% or more (Fig. 4.2).

Conversely, Firmicutes were more dominant in organically produced samples. In organic rocket, Firmicutes comprised up to around 70 - 80% of the microbial community, whereas their contribution decreased to approximately 40 - 50% in conventionally produced rocket (Fig. 4.2). This inverse relationship between Proteobacteria and Firmicutes suggests that production method strongly influences the phylum level structure of the vegetable associated microbiota

Results: Microbiome

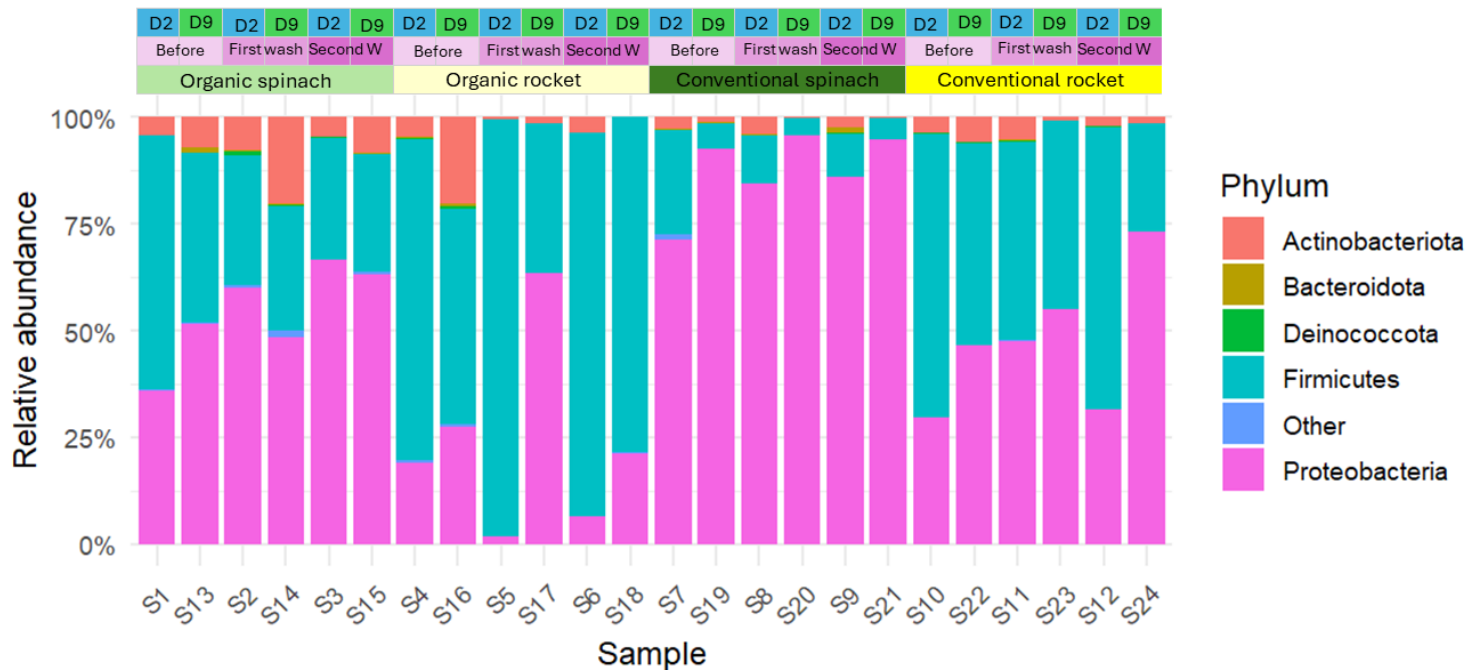


Figure 4.2. Five highest relative abundance phyla in samples

Results: Microbiome

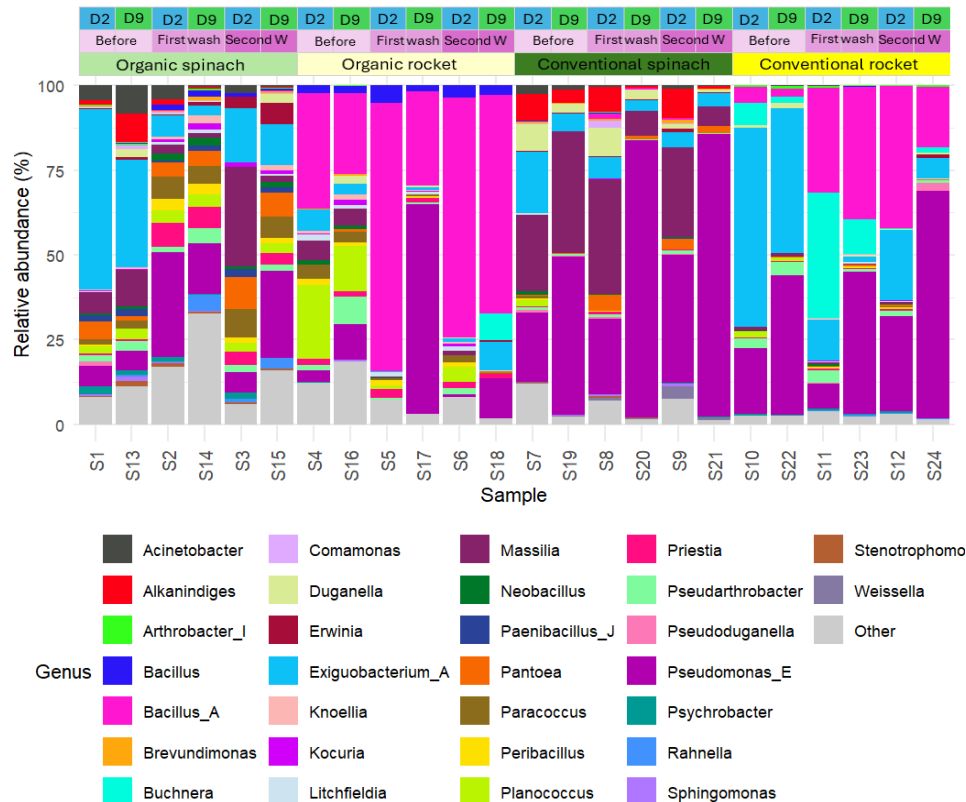
Bacterial microbiome using 16s RNA: Diversity of microbial community at genus level

At the genus level, the diversity is clustered based on spinach and rocket where spinach showed higher diversity in comparison with rocket (Fig. 4.3). In organic spinach (S1-S15 in the graph), the pre-wash sample (S1) was dominated by *Exiguobacterium_A*, accounting for more than 50% of the total relative abundance (RA) (Fig. 3.4). However, first washing step removed significantly amount of *Exiguobacterium_A* to under 10% RA, and increased considerably after second wash. In addition, the level of this genus is reduced slightly after 1 week storage at cold condition (Fig. 4.4).

The same pattern of *Exiguobacterium_A* changes in RA was also observed for conventional spinach, suggesting this organism is common in freshly harvested product, but easily removed/inactivated through washing. Although *Pseudomonas_E* was detected in the pre-wash sample, its relative abundance did not increase substantially during storage. In contrast, *Acinetobacter* and *Alkanindiges* increased markedly following repeated washing, with approximately two-fold and five-fold increases respectively. *Massilia* exhibited variable abundance across washing steps, becoming dominant after the second wash while remaining at low levels in pre-wash and stored samples.

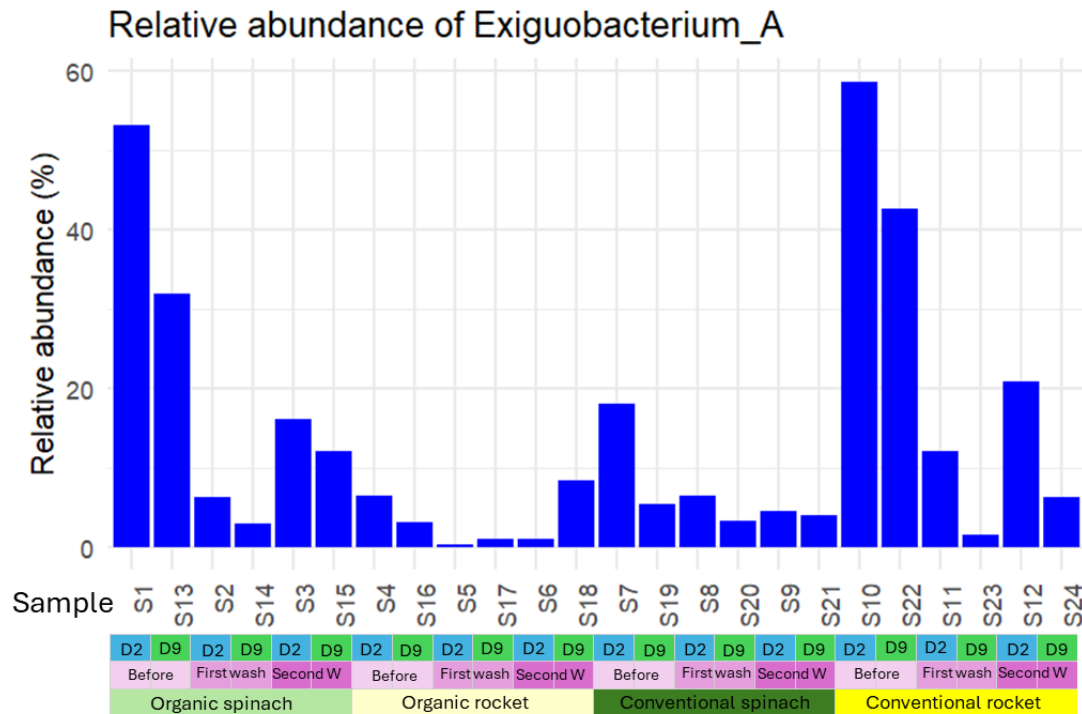
Results: Microbiome

Figure 4.3. Thirty highest relative abundance genera in samples



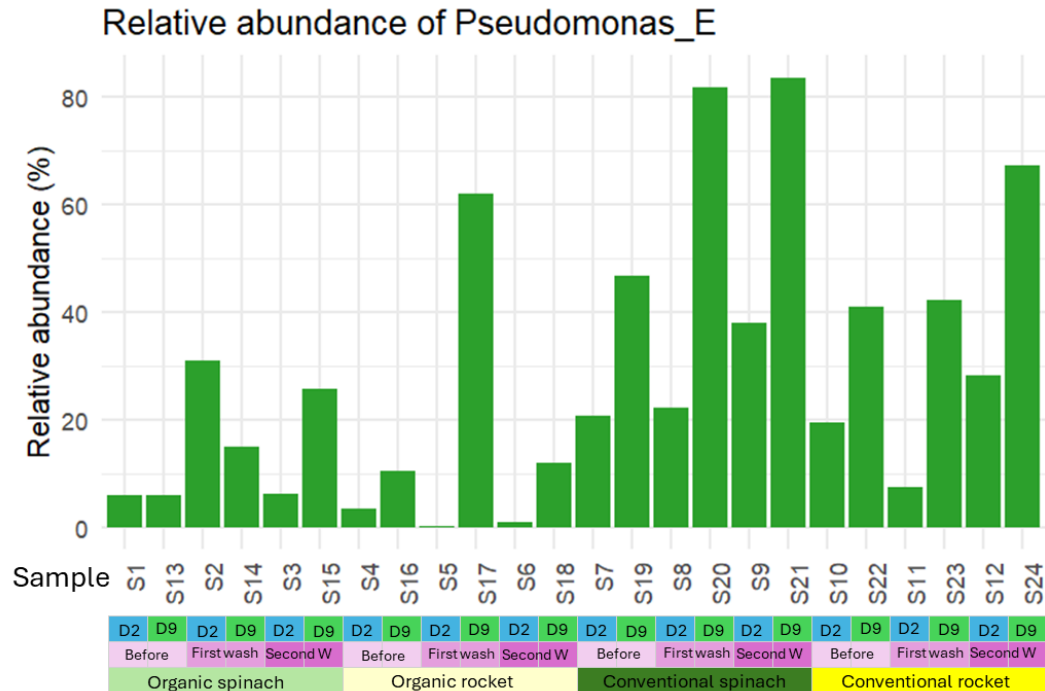
Results: Microbiome

Figure 4.4: Relative abundance of *Exiguobacterium_A* genus in all samples before and after storage



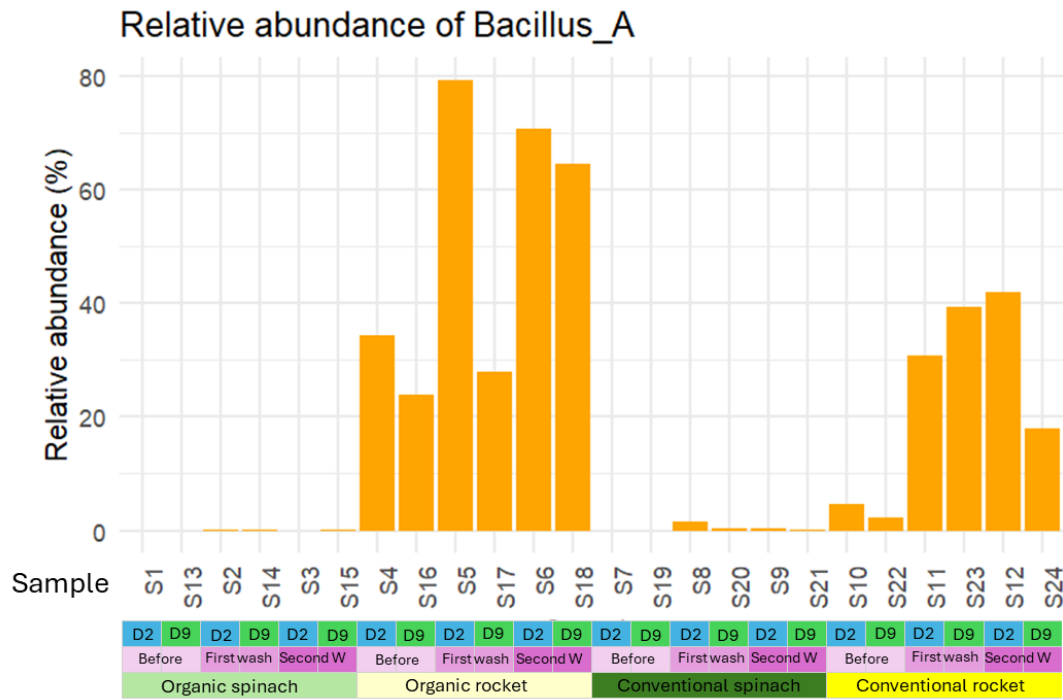
Results: Microbiome

Figure 4.5: Relative abundance of *Pseudomonas* genus in all samples before and after storage



Results: Microbiome

Figure 4.6: Relative abundance of *Bacillus_A* genus in all samples before and after storage



Results: Microbiome

Bacterial microbiome using 16s RNA : Diversity of microbial community at genus level

Organic rocket (S4–S18 in the graph) samples exhibited lower overall community diversity and were dominated by *Bacillus_A*. The relative abundance of *Bacillus_A* was approximately 40% at the initial sampling point and increased to nearly 80% following washing (S5, S6) (Fig. 4.6), before declining after cold storage. With the exception of sample S17, where *Pseudomonas_E* reached approximately 62% relative abundance, this genus was generally present at low levels.

In contrast to organic spinach, conventional spinach samples exhibited a higher relative abundance of *Pseudomonas_E*, which increased during cold storage. Notably, the washing steps did not reduce *Pseudomonas_E*; instead, its relative abundance increased from approximately 20% before washing (S7) to nearly double after two washing steps (S9) (Fig. 4.5) and increased markedly after one week of storage. Several samples (e.g., S20 and S21) were strongly dominated by this genus, exceeding 80% relative abundance. *Massilia* was the second most abundant genus in these samples; however, its relative abundance declined under cold storage conditions.

Results: Microbiome

Bacterial microbiome using 16s RNA: Diversity of microbial community at genus level

In conventional rocket samples (S10–S24), the bacterial community structure differed markedly from that observed in spinach and was strongly influenced by both washing and cold storage. Pre-wash samples (S10 and S22) exhibited moderate community diversity, with *Exiguobacterium_A*, *Pseudomonas_E*, and *Bacillus_A* contributing substantially to the overall microbiota. Prior to washing, samples were dominated by *Exiguobacterium_A*, accounting for nearly 60% relative abundance; however, this genus was markedly reduced after the first wash to approximately 10%, followed by a slight increase to around 20% after the second wash.

Similarly, the relative abundance of *Pseudomonas_E* decreased after the first wash and increased again after the second wash, rising from an initial level of approximately 20% to around 30%. In contrast, *Bacillus_A* showed a pronounced increase following washing, rising from nearly 5% before washing to approximately 50% relative abundance, before declining under cold storage conditions (Fig. 4.6). *Bacillus_A* was present in much higher levels in both rocket types (organic and conventional) compared to spinach, where it was present in low (<10%) abundance (Fig. 4.6).

Results: Microbiome

Bacterial microbiome using 16s RNA: Diversity of microbial community at genus level

Erwinia was detected in low levels in several samples, with species *E. persicina* most notably in organic spinach, where it was present at low relative abundance (~2%) in the pre-wash sample (Fig. 4.3). Its abundance increased after the third wash (~3%) and further increased during cold storage, reaching approximately 5% in the stored third-wash sample after 9 days.

Erwinia was not detected in organic rocket samples, but it was present at low levels in conventional spinach and appeared at low abundance (around 1%) in conventional rocket after the third wash during storage. Other genera, including *Massilia* and *Pantoea*, were detected intermittently but remained at comparatively low abundance.

Overall, these results demonstrate that washing and cold storage differentially influence bacterial community composition in leafy vegetables, with responses varying by vegetable type and production system.

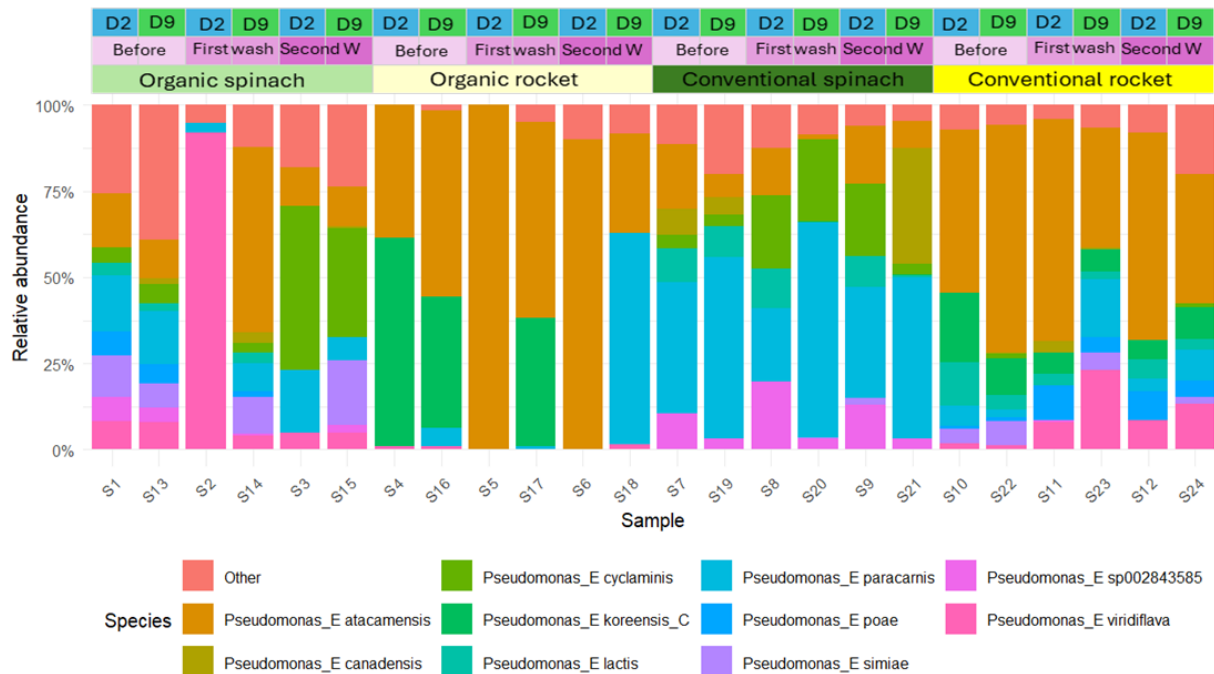
Results: Microbiome

The *Pseudomonas* species diversity

Pseudomonas spp. has been known as the spoilage factor for almost all vegetable products (Tournas, 2005). In this batch, there are multiple species of *Pseudomonas* present in samples. While *P. viridiflava* dominated after first wash in organic spinach sample, the *P. atacamensis* is dominated in organic rocket sample. *P. koreensis* is also popular in organic rocket. *P. koreensis* is a subgroup of *P. fluorescences*, a potential plant growth-promoting rhizobacterium (Guo et al., 2021). Similar to organic rocket, conventional rocket is also dominated by *P. atacamensis* while conventional spinach is populated with *P. paracamis* (Figure 4.7).

Results: Microbiome

Figure 4.7: Relative abundance of *Pseudomonas* species in all samples before and after storage



Results: Microbiome

The **Shannon diversity index** indicated higher microbial diversity in conventional spinach compared with organic spinach. In organic spinach, diversity increased significantly after the first wash and dropped again after the second wash. In addition, storage conditions also increased diversity. In contrast, microbial diversity in conventional spinach decreased slightly following washing and declined markedly after storage (Fig. 4.8).

Organic rocket exhibited higher initial diversity than organic spinach, however diversity decreased sharply during washing, with an approximately 50% reduction after the final wash. Notably, conventional rocket showed the lowest microbial diversity amongst all sample types and remained relatively stable across both washing and cold storage conditions (Fig.4.8)

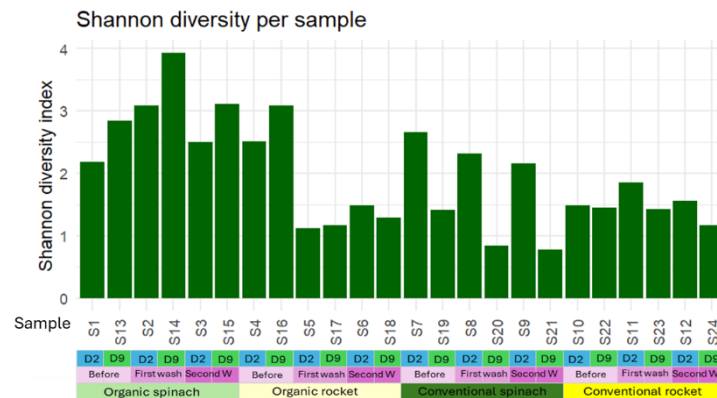


Figure 4.8: Shannon index of all samples, with the higher the number indicating greater diversity.

Results: Microbiome

Principal component analysis (PCA) using the top 10 most abundant genera revealed clear clustering of samples according to crop type and farming system (Fig. 4.9). PC1 and PC2 together explained 51.5% of the total variation in community composition. Organic and conventional spinach samples formed distinct clusters, with further separation between spinach and rocket, indicating that both crop type and production system strongly influenced the phyllosphere microbiome. There was less distinction between organic and conventional rocket samples. Within each cluster, samples collected after cold storage (Day 9) showed shifts primarily along PC2, suggesting that storage affected relative abundance without fundamentally altering community structure.

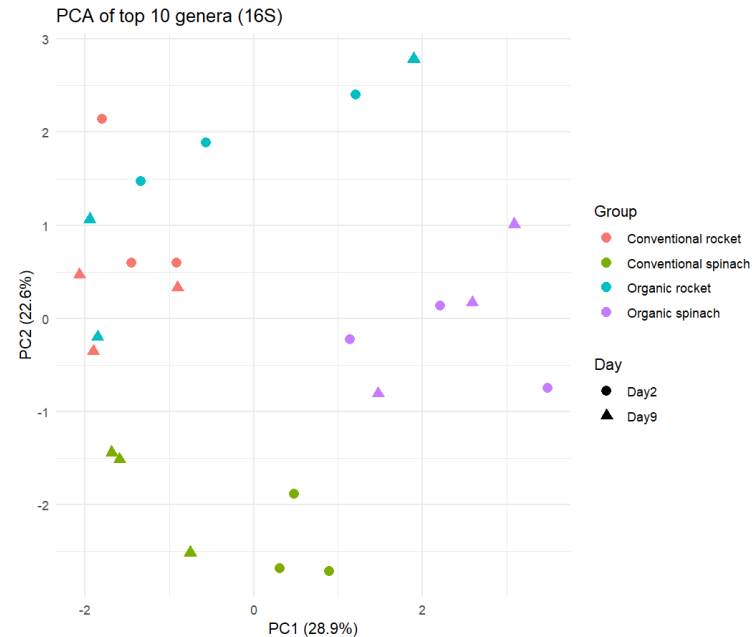


Figure 4.9: PCA of top 10 genera highest relative abundance in all samples

Conclusions

Spinach exhibited higher overall microbial diversity than rocket at the genus level, suggesting a more heterogeneous phyllosphere microbiome. In contrast, rocket samples frequently showed low diversity and strong dominance by one or two genera, particularly in organic farming methods.

Organically produced spinach and rocket were characterised by a higher relative abundance of Firmicutes, particularly *Exiguobacterium_A* and *Bacillus_A* respectively, whereas conventionally produced samples were dominated by Proteobacteria, especially *Pseudomonas_E*.

At the genus level, organic rocket was consistently dominated by *Bacillus_A*, while organic spinach showed higher representation of *Exiguobacterium_A* prior to washing. In contrast, conventional spinach and rocket were frequently dominated by *Pseudomonas spp.*, particularly following washing and storage.

Conclusions

Peroxyacetic acid washing resulted in an immediate reduction in total bacterial load; however, its impact on community composition was selective rather than uniform. Washing substantially reduced the relative abundance of *Exiguobacterium_A*, particularly in organic spinach and conventional rocket.

In contrast, *Pseudomonas_E* was not effectively reduced by washing and, in several cases, increased in relative abundance following successive washes. This was most evident in conventional spinach.

***Bacillus_A* showed a pronounced increase in relative abundance following washing in both organic and conventional rocket, likely reflecting its resistance to chemical stress and potential persistence as spores or stress-tolerant cells.**

Recommendations Summary

- Triple washing should be adopted as the preferred method for the washing and sanitisation of spinach and rocket, as it is expected to deliver improved shelf life and better microbial outcomes.
- *Bacillus* species are more commonly associated with rocket leaves than with spinach.
- Current evidence indicates that peracetic acid (PAA) has limited efficacy in controlling *Bacillus* during the washing and sanitisation process. Even at concentrations exceeding 100 ppm, PAA has not demonstrated significant effectiveness. Research has also shown this.
<https://pubmed.ncbi.nlm.nih.gov/16924915/>
- Export market requirements, particularly those of Singapore, should be carefully considered when exporting rocket leaves and mixed leafy salad products containing rocket.
- The Safe Leafy Veg team will be conducting trials to investigate strategies for managing *Bacillus* (particularly in rocket leaves), including evaluation of a dual-sanitiser approach subject to funding approval from Hort Innovation.

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Primefact

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

April 2025, Primefact PUB25/305, first edition

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Introduction

Shiga toxin-producing *Escherichia coli* (STEC) are a sub-group of *Escherichia coli* (*E. coli*) bacteria that produce toxins known as 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 like 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 characterised by Shiga toxin (Stx) production. 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 (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 and the annual rate of cases (1.99 cases per 100,000 per year) increased significantly during this period (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 contrast, in humans, the presence of additional virulence factors alongside the *stx* gene are 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 in their ability to 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 is using contaminated water for irrigation. Water contaminated with faecal matter from animals (livestock and wildlife) can carry pathogens like 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 1), particularly closer 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.



Figure 1. Applying contaminated surface irrigation water with an overhead irrigation system elevates the risk of leafy vegetables contamination.

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 through direct contact with soil or indirect splashing with rain and overhead irrigation.
3. **Growing site:** the coexistence 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 come into contact with 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 postharvest processing.
6. **Postharvest 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 2).
7. **Extreme weather conditions:** heavy rainfall that results in run-off or flooding (Figure 3), dust storms, bushfires and heatwaves affect fresh produce safety (Singh 2023). Natural disasters often exacerbate the transfer of microbial pathogens from the environment into production fields, water sources and postharvest processing facilities.



Figure 2. The wash water must have appropriate sanitiser concentrations.



Figure 3. Extreme weather conditions such as heavy rainfall can transfer microbial pathogens from the environment into production fields, water sources and postharvest 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:

Preharvest water quality management: irrigation water from surface sources such as rivers and canals should be pumped and stored in a dam/pond to allow the suspended solids to settle. The presence of 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 4).

Irrigation water quality should be monitored regularly (Figure 5), 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 4. Using coarse filtration and frequent backflushing minimises the sediment and reduces the microbial population in irrigation water.



Figure 5. Collecting samples to test irrigation water.

Organic soil amendments:

composts containing animal manure should be free from harmful pathogens (Figure 6). Commercial products must be treated in accordance with the [Australian Standard AS4454-2012 Composts, soil conditioners and mulches](#). Traceability of composts containing animal products (e.g. source, batch, certification) sourced and applied in the production system is important to take corrective actions if required.

Coexistence 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. Cattle, in particular, are considered one of the highest-risk animals for STEC contamination. Extreme weather conditions (e.g. dust storms, heavy rainfall, cyclones) influence the transmission and spread of contamination within the broader environment surrounding cattle operations. Proper drainage systems should be installed to curtail run-off risk from neighbouring animal operations.



Figure 6. Microbiological sampling of compost samples.

Harvest and postharvest management

- Harvest equipment hygiene is crucial to manage 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 postharvest 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 leafy processing should have an appropriate sanitiser concentration in each washing and sanitising tank (Figure 7).
- 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 in the event of an outbreak or product recall. Proper documentation of each stage of the supply chain is essential for efficient trace-back procedures. Growers should maintain records of all farm inputs such as soil amendments, fertilisers and water used for leafy vegetable production and processing.



Figure 7. Appropriate sanitiser concentrations should be in each washing and sanitising tank.

Microbiological testing

To ensure production practices, processing operations, and end products are safe, microbiological testing should be conducted. In addition to the routine testing for quality assurance, growers and processors should test produce, soil and water in response to product recalls, food safety incidents and natural disasters such as floods and cyclones. **Testing is a resource-intensive process and should be based on risk levels.** Whether testing is required for produce, soil or water, should be based on the following risk factors:

Produce testing

If the crop is:

- irrigated with overhead sprinklers using water with high levels of *E. coli* (>100 CFU/100mL).
- grown in soil amended with organic products (e.g. fresh and aged animal manure).
- exposed to extreme weather conditions (e.g. heavy rainfall, dust storms).
- near livestock operations.
- grown in the field where animals have been grazing before the crop is planted.

Soil testing

If the production field is:

- exposed to extreme weather conditions (e.g. flooding).
- amended with organic products (e.g. fresh and aged animal manure) in the previous year.
- grazed by animals before the crop is planted.

Water testing

If the surface water:

- is exposed to extreme weather conditions (e.g. flooding).
- is used for overhead sprinkler irrigation, particularly in summer months.
- has historically high levels of *E. coli* (>100 CFU/100mL).
- is close to intensive livestock operations and is prone to upstream contamination.

Preharvest testing of leafy vegetables

Reyes et al. (2023) developed a leafy vegetable supply chain model and predicted that product testing is most effective when conducted early in the system before interventions (e.g. washing).

Preharvest testing of leafy vegetables is thus an effective strategy to mitigate food safety risks. In the USA, the California Leafy Greens Handler Marketing Agreement (LGMA) developed comprehensive guidance for both routine and risk-based preharvest sampling and testing protocols for leafy vegetables. Detailed information can be obtained from [California LGMA's website](https://lgma.ca.gov/) (<https://lgma.ca.gov/>).

During natural disasters and responses to recalls/outbreaks, risk-based sampling and testing protocols are appropriate.

Briefly, the following considerations for sampling lot and size should be undertaken for preharvest testing:

- Preharvest sampling: <7 days from harvest.
- Sampling lot: 1 acre (0.4 hectares) or less.
- Divide a 1-acre lot or field-level block into a grid and conduct systematic sampling within each grid, starting at a randomised location with a predetermined spacing. For example, every third bed and approximately every quartered position of the bed length within each grid.
- **Total sample size: 1,500 g** with minimum $n = 60$ from an acre or less.
- Target pathogens: presence/absence of STEC, *Salmonella*, *Listeria monocytogenes* and generic *E. coli* population.

Low-level and widespread contamination is more likely to be detected with a larger total composite sample mass (Quintanilla Portillo et al. 2022). Therefore, preharvest sampling is more effective when taking an increased number of smaller samples with randomisation. An example of a sampling plan adapted from LGMA is in [Table 1](#).

Table 1. 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

Grab specimens should include plant tissue collected from multiple heads/plants. Sub-samples comprised of a composite of leaves should be tested as a unit. That means 4 sub-samples (375 g each) for an acre of iceberg lettuce field should be submitted to the testing laboratory.

Generally, a sub-sample of 25 g is taken from a larger collection of samples. However, sampling size and methodology have evolved towards analysing larger masses of samples, especially for fresh leafy vegetables. To test the entire mass of 1,500 g, 4 sub-samples of 375 g or 10 sub-samples of 150 g should be analysed. Laboratories should have validated methods to analyse up to 375 g in a single enrichment. Based on long-established guidance, statistical assumption requires that all sample material (i.e. $n = 60$ totalling 1,500 g) be used for laboratory analysis.

Leafy vegetable growers and processors affected by natural disasters (e.g. cyclones, heavy rainfall) should discard the leafy vegetable crops that have been in direct contact with floodwater or heavy run-off. Replanting should be considered after at least a 60 day waiting period or after 30 days if the soil microbiological testing meets the standard of compost testing (California LGMA).

Testing of soil

Divide a 1-acre lot or field-level block into a grid and conduct systematic sampling within each grid, starting at a randomised location with a predetermined spacing. For example, every third bed and approximately every quartered position of the bed length within each grid.

Surface soil swabs: these can be collected by aseptically wearing sterile boot covers/ swabs and walking along the crop bed (Figure 8) for at least 50 meters. Fifteen pairs of boot covers ($n = 30$) should be collected from one acre. Alternatively, sponge swabs can be used to collect soil drags. Aggregate boot cover sampling has been shown to be a more representative and practical method for preharvest soil testing than grab sampling (Wu et al. 2023).

Soil grab samples: collect at least 30 sub-samples of 100 g from each location to make a composite sample of 3,000 g and then mix thoroughly to draw a 300 g test unit. Collect at least 5 composite samples (~300 g each) to a depth of 50–75 mm with a soil sampling tool from an acre of field.



Figure 8. Collecting surface soil samples by aseptically wearing sterile boot covers.

Testing of irrigation water

Microbiological testing of irrigation water should be undertaken to determine the population of generic *E. coli* and the presence of other target pathogens.

- For each water source, at least 3 samples should be collected from the point of application (i.e. sprinklers) and locations closest and farthest from the water source.
- Allow the irrigation system to run for a while (e.g. 3–5 minutes) before collecting samples to ensure the water sample is drawn from the irrigation source and not the residual water in the pipe line.
- Additional sampling can be conducted from primary water sources such as rivers/canals/ponds.
- From each location, collect one litre of water in sterile sampling bottles containing sodium thiosulfate.

Postharvest water testing and monitoring

Water is an important element in postharvest processing of leafy vegetables and its quality determines food safety outcomes. Growers and processors should undertake following measures:

- Microbiological testing of postharvest water used for washing produce and equipment (produce contact surfaces in particular), and workers' facilities should be tested to ensure it meets drinking quality requirements. The samples (one litre each) should be collected from various taps and outlets supplying washing tanks, cleaning hoses and workers' facilities.
- Processors should monitor the concentrations of sanitisers and contact time of leafy vegetables with sanitised water. Automated sanitiser dosing systems should be verified by manual measurement of sanitiser concentrations at regular intervals.
- Increasing the sanitiser concentration and contact time could compensate for the potentially increased microbial load on leafy vegetables exposed to extreme weather conditions. Additionally, wash water chemistry parameters such as pH, turbidity, and oxidation-reduction potential (if applicable) should be monitored regularly.
- Microbiological testing of wash water from processing tanks/flumes for generic *E. coli* and other pathogens is suggested as a measure to minimise cross-contamination risks and to verify the efficacy of sanitisers in washing process.

Testing processed products for target pathogens such as *E. coli*, STEC, *Salmonella* and *Listeria monocytogenes* is suggested; and follow the 'test and release' system. A sample size of 375 g is recommended.

All types of samples should be placed in an insulated container with sufficient freezer bricks/ice packs to keep them cool during transport. These samples should arrive in the testing laboratory within 24 hours of collection.

Conclusions

The contamination of leafy vegetables with STEC poses a significant public health risk, particularly for raw and minimally processed products. The risks can be mitigated through a combination of preventative and detective control measures, both during production and postharvest processing. A comprehensive, multi-faceted approach to risk management is essential for reducing product recalls, preventing the incidence of foodborne illnesses linked to STEC contamination in leafy vegetables, and ensuring safe, high-quality produce for consumers.

Food safety helpdesk

The food safety helpdesk service is available to leafy vegetable growers and processors to answer technical enquiries confidentially. For further information, contact Dr SP Singh on sp.singh@dpi.nsw.gov.au or 0420 593 129.

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Safe Leafy Veg

Best practice guidance



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Dr Sukhvinder Pal (SP) Singh

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Safe Leafy Veg Best practice guidance

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Introduction

The Safe Leafy Veg program, conceptualised and led by the NSW Department of Primary Industries and Regional Development (NSW DPIRD), is a food safety initiative designed to reduce microbial risks in leafy vegetable production and postharvest 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 microorganisms, 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.

Recognising these risks, NSW DPIRD has taken a proactive, science- and data-based approach to strengthen food safety outcomes for the leafy vegetable industry through the Safe Leafy Veg program (VG22002). The program is supported by Hort Innovation, the Australian Government, and industry levies. It builds on lessons learned from earlier commodity-specific initiatives, including the Safe Melons program, which showed that targeted research combined with strong industry engagement can significantly reduce food safety risks.

A central component of the Safe Leafy Veg program is comprehensive microbial risk mapping in the leafy vegetable supply chain. Since starting in 2023, NSW DPIRD researchers have worked closely with growers and processors in major production regions to examine on-farm and postharvest practices in detail. This has involved site visits, observational assessments, and the collection of 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 key pathogens and indicator organisms to identify where contamination is most likely to occur and how it might spread or persist within production systems.

Industry engagement has been a defining feature of the program. Growers 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 better understand their own risk profiles and identify practical opportunities for improvement.

By working collaboratively, NSW DPIRD has positioned the program as a supportive tool for industry improvement rather than a compliance exercise.

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 reservoirs of contamination 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.

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 growers and processors with the scientific evidence, practical guidance, and confidence needed to meet these obligations and transition smoothly into the new regulatory environment.

Overall, the Safe Leafy Veg program represents a forward-looking, scientific evidence- and data-driven approach to food safety in the leafy vegetable sector. 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 throughout the sector, ensuring that leafy vegetables remain a safe and trusted component of the Australian food supply.



Major food safety challenges for leafy vegetable growers

The Safe Leafy Veg project team identified several recurring food safety challenges faced by leafy vegetable growers. While many food safety risks can be managed through good agricultural and processing practices, growers operate in a complex production 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, droughts and heatwaves 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 growers. 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 adjacent land uses can act as sources of foodborne pathogens that can be transported onto production sites through run-off, dust, aerosols, flooding, wildlife movement or equipment traffic. Implementing effective mitigation measures remains a significant challenge for many growers.
- **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. Growers 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/verification programs were frequently identified by growers as a major challenge.
- **Balancing sustainability and environmental outcomes with food safety:** growers are increasingly expected to deliver both food safety outcomes and environmentally sustainable production practices. Horticultural and livestock industries have long co-existed and played an important role in nutrient recycling and sustainable agricultural systems. While the

use of 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, area-wide, approach that integrates food safety, environmental stewardship and operational viability.





Mind the W framework

This 'Mind the W' framework (Figure 1) has been developed using **findings** from the Safe Leafy Veg project, one of the most comprehensive investigations of microbial food safety risks undertaken within the Australian leafy vegetable industry. As part of the project, current industry practices relating to production, harvesting, packing and processing were reviewed to understand the factors influencing microbial contamination risks along the supply chain. Extensive engagement with growers, processors and industry stakeholders was undertaken to ensure the framework reflects both scientific evidence and the practical realities of commercial leafy vegetable production.

The Mind the W framework identifies 7 interconnected risk areas:

1. **W**ater use before and after harvest
2. **W**aste from animal operations
3. **W**ildlife and animal incursions
4. **W**ind from animal operations
5. **W**eather extremes
6. **W**ashing and sanitisation
7. **W**orkers' health and hygiene (Singh et al. 2025).

Together, these 'Ws' represent the most significant pathways through which microbial contamination can 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 postharvest action. The Mind the W framework is designed to simplify communication of complex food safety concepts and improve adoption of best practices by growers 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 supports 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 *E. coli* and *Salmonella* spp. into soil, where they might persist for extended periods. These pathogens can then contaminate crops directly through splash, 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 to support traceability and informed risk assessment.

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 near or within fields can compromise the safety of future plantings. Risk management in this area focuses on prevention and early detection through 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 facilitating the movement of contaminants throughout 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. Floodwaters, in particular, 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 effect of extreme conditions.

Postharvest washing and sanitisation are critical steps for managing microbial risks, but can become points of failure if poorly controlled. Inadequate sanitiser levels, excessive organic matter, or poorly maintained equipment 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 achieve effective pathogen reduction, 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 initiative, this framework provides a practical and accessible guide for managing complex risks throughout the production and postharvest 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.



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 growers and processors.





Best practice guidance

This document provides guidance on best practice recommendations based on scientific research, food safety data, industry practice and other international resources from leading regulators and industry organisations. However, it is not an interpretation of the Food Standards Code and does not have legal force.

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](#).

The Standard generally applies to leafy vegetables and herbs that are supplied fresh and are 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 scope.

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, microgreens, spring onions	Coriander (cilantro), Parsley, Basil, Mint, Dill, Oregano, Sage, Thyme, Other leafy herbs commonly consumed raw or minimally processed

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, microgreens).
- **Growing site:** any site where leafy vegetables are grown, including fields, greenhouses, tunnel houses and hydroponics. It includes both soil and soilless cultivation of leafy vegetables under open, partially covered and fully covered facilities, including vertical farming.
- **Harvest:** all activities associated with the harvesting of 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, packhouses, precoolers, 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 it. An FSMS template has been developed as an example and is included in Appendix II. This statement must:

- Identify potential hazards (microbial, 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, and activities undertaken, and update information as required.

Producers and processors are responsible for managing hazards relevant to their own production and processing steps.

Hazards for leafy vegetables include:

- **Microbial:** Shiga toxin-producing *E. coli* (STEC), *Salmonella* spp., *Listeria monocytogenes*.
- **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 that are 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 product **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 exact 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.

An effective traceability system should include:

- Traceability process: clear procedures for recording producers, suppliers, customers, and product details
- Supplier details: name, address, phone, email, plus a description of the products or inputs supplied.
- Customer details: name, address, phone, email, along with a description of the products supplied.
- Transaction records: dates of delivery or sale.
- Identification codes: batch numbers, lot codes, or other product markings.
- Quantity records: amounts of product 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 key 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 a contamination occurs, businesses can quickly determine whether a particular water source or soil amendment batch was involved. Effective input traceability not only supports rapid response and corrective action but also limits the scope of recalls, protecting both public health and business continuity.



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

Inputs – seed, seedling, 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, soilless substrate, soil amendments (such as manure, biosolids, compost, and plant bio-waste), fertilisers, and water.

Seed and seedling

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

Salmonella and *E. coli* 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 and fenugreek compared to 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

Contamination with human pathogens in hydroponic systems poses a significant food safety concern (Figure 4). The closed, water-based environment can facilitate the introduction and spread of microorganisms such as *Salmonella*, *Listeria*, and noroviruses.



Figure 4. Hydroponic production of leafy greens in a semi-enclosed facility.

While hydroponic cultivation is often considered a risk-reducing alternative to soil-based production systems, evidence shows that pathogens can persist in nutrient solutions and even internalise into plant tissues, especially if system hygiene is compromised or contaminated water sources are used (Gibbio et al. 2019; 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 project indicate that the root zones of hydroponically grown leafy vegetables are hotspots for pathogen detection, likely because roots provide pathogens with opportunities for attachment and growth, which is similar to the published reports (Ilic et al. 2022). The presence of pathogens in the root zone has potential for contamination of edible leaves during harvest and postharvest handling, including display at retail due to stacking.

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



Figure 5. Hydroponic production of Asian vegetables in a fully enclosed facility.

Field production of leafy vegetables

Soil serves as a reservoir for human pathogens such as *Listeria monocytogenes*, which can persist for long periods under favourable conditions. These pathogens can transfer to crops during growth, colonising roots and above-ground tissues. 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 6. Field production of leafy vegetables.

Soil texture significantly influences the survival and diversity of human pathogens such as *Salmonella* and *Listeria*, 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 potential human pathogens, by providing more attachment sites and shielding them from environmental stresses. This increases their persistence in the soil environment (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 result in 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 *Salmonella* and *Listeria* by providing a stable micro-environment that enhances their survival and diversity. This highlights the importance of considering soil physical properties in 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 vehicle 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 lead to localised contamination on leaves and stems. Moreover, this adherence increases the risk of cross-contamination within processing facilities, where residual soil on machinery can serve as 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.

DRAFT



Organic soil amendments

Organic amendments, including compost, manure, and plant residues, play a critical role in enhancing 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 has been shown to enrich beneficial microbial communities, suppress soilborne pathogens, and elevate concentrations of bioactive metabolites that further support 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, however, is influenced by factors such as amendment type, soil pH, texture, climate, and crop species.

Compost

Composts containing plant residues and animal manure are generally regarded as safe from a microbial food safety perspective. The composting process can effectively inactivate or kill harmful foodborne bacterial pathogens when key parameters such as temperature, aeration, moisture, and turning are properly maintained ([Figure 7](#)). However, the process does not guarantee the elimination of all pathogens, as some thermotolerant and spore-forming bacteria (e.g. *Clostridium botulinum*) might survive. In addition, the bulky nature of organic material can result in uneven time–temperature exposure, creating potential escape zones where pathogens might persist and regrow later.

In Australia, composts that meet the requirements of Standard AS4454–2012 are considered safe for use in fresh produce production. The standard specifies that:

- **Low-risk materials** (e.g. plant matter, vegetation) must undergo at least three 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 five 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 a microbiologically safe product. However, the testing of the final product ([Figure 8](#)) for meeting Australian standards versus state regulators could vary, as shown in [Table 2](#).



Figure 7. Windrow composting of spent mushroom substrate on a farm.



Figure 8. Sampling of compost for microbiological testing.

The **AS4454–2012 standard for composts, soil conditioners, and mulches** is currently under revision. 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 composts and organic amendments are traded interstate.

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)	Victoria EPA (Processed Organics 2021)
Faecal coliforms	<1,000 MPN/g dry weight	<1,000 MPN/g	<1,000 MPN/g dry weight
<i>Salmonella</i>	Absent in 50 g dry weight	Absent in 25 g	Absent in 50 g dry weight
<i>E. coli</i>	–	<100 MPN per g	<100 MPN per g

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 shifts, 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.

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*) and viruses (e.g. adenoviruses), which might persist through the composting process (NSW DPE, 2023) and present transmission risks when organic amendments are applied to fresh produce. These risks demonstrate the need for the updated AS4454 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 composts containing animal-derived inputs must be:

- Tested and shown to be free of *Salmonella* and Shiga toxin-producing *E. coli* (STEC),
 - Verified to contain faecal coliforms <100 MPN/g of dry solids, and
 - Applied at least 45 days before harvest to reduce the risk of pathogen transfer to crops.
- Beyond composts, the 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 composts that comply with AS4454–2012 and relevant jurisdictional organic recycling regulations,
- Requiring growers 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 the AS4454 standard, and
- Conducting additional microbiological testing of composts for priority pathogens such as STEC and *Listeria monocytogenes*, as a verification step beyond compliance testing.

Together, these evolving requirements reflect a broader paradigm shift in the management of organic amendments 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

The application of 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 farm systems, crop rotation schedules, and availability of organic amendments.

More commonly, growers incorporate poultry litter or cattle manure into the soil before planting. In addition, the use of aged manure and, in some cases, composted amendments as side dressings for leafy head crops or top dressings for spring onions has been observed.

Importantly, untreated manure used on farm is rarely applied fresh. Instead, they are usually stored for days or weeks before application. During storage, manure piles might heat internally, which could reduce, but not eliminate, pathogens. However, because piles are not actively managed or aerated, heating is uneven, and pathogen die-off is inconsistent.

Aged manure should therefore not be considered equivalent to compost, which undergoes a controlled process to reliably reduce pathogens. From a food safety risk perspective, aged manure occupies a 'middle ground' between untreated raw manure and fully composted material.

A further complication is the mixing of compost with raw manure, which some growers practice to balance soil fertility, but increases uncertainty about microbial safety outcomes.



Figure 9. Appropriate storage of organic amendments on a concrete floor and walled area that is isolated from field production areas.

The survival of foodborne pathogens in manure-amended soil is highly variable, influenced by both environmental and management factors. Pathogens such as STEC, *Salmonella* spp., and *Listeria* 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 10. Storing organic amendments next to the crop can increase the risk of airborne microbial contamination.

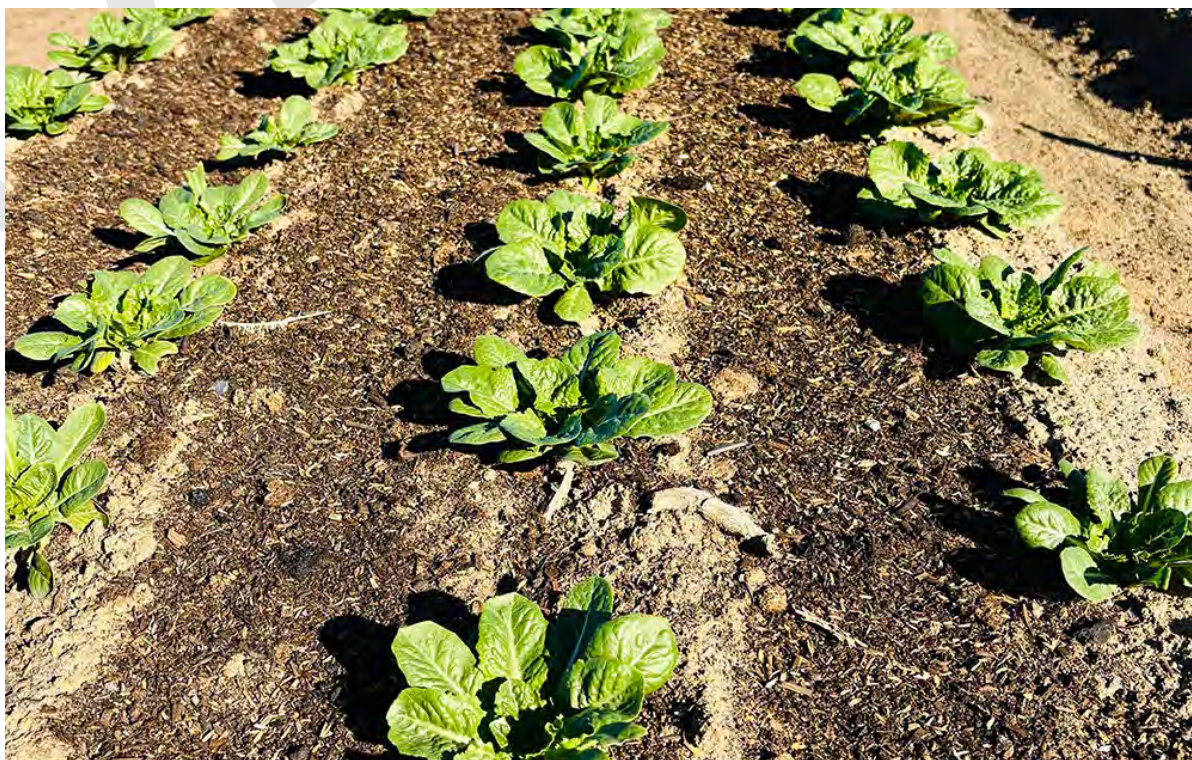


Figure 11. Applying organic amendments as a top or side dressing over the crop canopy is high risk for produce contamination.

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 for untreated or partially composted amendments, which can be reduced to 270 days if supported by soil testing and a documented risk assessment.

Prevalence of pathogens in soil

Field data suggest that soil amended with untreated manure might not be the primary source of food safety risks compared with irrigation water. In the Safe Leafy Veg program, random soil sampling has shown a low prevalence of pathogens (*Salmonella*, *Listeria monocytogenes*, STEC) relative to irrigation water. Similarly, a large California study found only 0.64% prevalence of STEC in soil (N=4,900 samples), significantly lower than in water sources (Cooley et al. 2013).

This evidence supports the approach, taken by FDA and Safe Leafy Veg, to focus on data collection that better characterises pathogen prevalence and survival in soil and amendments under diverse farming conditions. Key priorities include:

- Pathogen prevalence in raw, aged, and composted manure
- Survival dynamics and transfer risks to produce
- Documentation of on-farm practices affecting risk
- Development of mitigation strategies to manage risks in a practical and scientifically validated manner.

Organic amendments versus sustainability and profitability

Growers use untreated raw or aged manure in light-textured soil because of their clear agronomic benefit, 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 growers 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 growers' ambitions to farm more sustainably. Many growers see organic amendment use as a pathway to reduce reliance on

synthetic fertilisers, lowering nutrient losses, and decreasing water use, outcomes that align with broader environmental and climate goals.

Yet, despite these perceived benefits, growers remain acutely aware of the food safety risks. To overcome them, they adopt a variety of mitigation strategies, including microbiological testing of manure before application, planting cover crops after manure incorporation, 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 growers 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, growers 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 (AS 4454–201) for composts.
- 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 transitioning back to leafy vegetable production.
- 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 to support 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, such as:

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 *Salmonella*, STEC, and *Listeria monocytogenes*, allowing them to survive and multiply in the solution.

2. Optimal temperature and pH

Hydroponic systems are often maintained at temperatures (typically 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 stresses and sanitisers, allowing them to persist over 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 the growth, survival, and dissemination of foodborne pathogens. Even low-level contamination can escalate rapidly, making rigorous water monitoring, sanitation, and pathogen control essential in hydroponic leafy vegetable production ([Figure 12](#)).



Figure 12. In hydroponic production systems, recirculating nutrient solutions can support 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 sprays, frost and heat protection can serve as a direct vehicle for the introduction of 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 lands. When pathogens such as *Salmonella*, STEC, or *Listeria monocytogenes* are in irrigation water, they can be introduced directly onto leafy tissues such as lettuce, spinach, or kale, where they might persist until harvest and potentially survive postharvest 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, surface 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 with 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, growers use a broad range of water sources, each with distinct hydrological characteristics, operational advantages, and food-safety implications.

Surface water sources such as rivers and creeks 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 settling of sediment, yet remain open to wildlife, livestock access, and storm-driven contamination.

Freshwater springs provide relatively protected, consistent flows and are known for generally higher baseline quality, but are not immune 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 preharvest uses when collection systems are well maintained. However, its availability is directly constrained by rainfall patterns 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 entirely 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 creeks 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 sediments and particulate matter to drop out of the water before irrigation. This sedimentation process is not only important for preventing clogging of drip or sprinkler systems, 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 application to crops (Figure 14).



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

Data from the Safe Leafy Veg project has demonstrated that this management step can have a measurable effect on microbial risk. Specifically, storing river water in ponds was shown to reduce *E. coli* populations by up to ten-fold, largely attributable to sedimentation, natural die-off processes, and in some cases exposure to sunlight (UV radiation) within the storage system. Such reductions are critical given that leafy vegetables are typically consumed raw and therefore present no further 'kill step' to eliminate pathogens before consumption.

Further improvements in water quality can be achieved when pond-stored water is passed through filtration systems before field application. The use of coarse filters to remove larger organic matter, combined with frequent backflushing to maintain filter performance, has been shown to substantially reduce particulate loads and further limit 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, and microbial loads can fluctuate sharply following 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 microorganisms onto leafy vegetables.

The practice of storing river water in farm ponds, optionally blending it with groundwater, and applying filtration before irrigation represents 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). Trends observed from multiple water sources from different regions indicate that *E. coli* counts are generally higher during the hotter summer

months (November to February) and following heavy rainfall and flooding conditions, when contaminated run-off from adjacent land uses, including livestock operations, manure-amended soil, or urban effluent discharges, 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 STEC, *Salmonella* and *Listeria monocytogenes* in irrigation water.



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

Currently, annual monitoring of irrigation water is widely practised by leafy vegetable growers as part of 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, growers 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, growers can establish baseline microbial profiles for each water source, identify recurring high-risk periods, and make more informed decisions on water quality. In practice, this means that water quality management should go beyond compliance-based testing and instead focus on an integrated systems approach that combines regular monitoring with preventative 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, grounded in 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.



Figure 16. Water sources can be affected by drought.

Risk assessment

A water risk assessment 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, enabling the implementation of effective control measures to prevent contamination. This system-based approach requires continuous assessment and mitigation to ensure water safety from source to application.

- 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.
- Next, the system is mapped, documenting sources (surface, groundwater, municipal, treated), storage, conveyance, treatment, sampling points, and potential cross-connections or backflow risks.
- 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 triggers (heavy rain, heat, flooding), and historical microbial data.
- Based on this assessment, growers decide 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.
- 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.

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 is expensive and time-consuming, most programs rely on indicator organisms such as generic *E. coli* and total coliforms. The main goals of microbiological testing of water 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, flooding, temperature fluctuations, and surrounding land use. Standard testing methods typically assume that microorganisms 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.

E. 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* or STEC (Holvoet et al. 2014), pathogens can still be present when *E. coli* concentrations are low, and vice versa. Water samples have shown a seasonal pattern, with both pathogens and indicator bacteria more frequently detected during warmer months (Shelton et al. 2011).

For instance, a study in Canada found pathogens in 80% of agricultural water samples that had low *E. coli* concentrations (<100 cfu/100 mL), highlighting the risk of relying solely on *E. coli* (Edge et al. 2011). Similarly, research in Central Florida revealed that although all tested agricultural water ponds met the microbial water quality standards outlined in the U.S. 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 further support these findings. Water samples meeting irrigation quality criteria (*E. coli* <100 cfu/100 mL) contained pathogens such as *Salmonella*, STEC, and *Listeria monocytogenes*. In fact, one in four 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.

The Safe Leafy Veg program recommends direct/target pathogen (e.g. *Salmonella* and STEC) testing for surface irrigation water (e.g. rivers, creeks, ponds) source if it:

- has historically high levels of *E. coli* (>100 CFU/100mL)
- used for overhead sprinkler irrigation, particularly in summer
- is close to intensive livestock operations and is prone to upstream contamination
- is exposed to extreme weather conditions (e.g. flooding)

Achieving statistically reliable results also requires frequent sampling, which can be prohibitively costly for smaller growers. To manage risk effectively, growers 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.



Figure 17. Water sampling from an irrigation channel after heavy rainfall, showing poor water quality.

Physical and chemical treatment of water

A range of physical and chemical treatment strategies has 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, growers 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 within 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 technologies, employing 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.

The Safe Leafy Veg data showed that the use of coarse filters to remove larger organic matter, 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, 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.

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



Figure 18. Irrigation water treatment set-up on a farm.

Future research

The Safe Leafy Veg program is aimed at providing cost-effective and practical solutions for growers, focusing on minimising microbial risks associated with irrigation water. As part of this initiative, field-scale trials will be conducted on growers' 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* and *Cyclospora*, 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 two days of harvest of leafy vegetables, which is practically challenging for large-scale production. To overcome this, the program will engage stakeholders, regulators, and growers 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.





Growing sites

Risk assessment 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 human pathogens. Potential sources include, but are not limited to, manure storage areas, composting facilities and operations, animal operations (e.g. dairy, poultry), grazing lands (Figure 19), domestic animals or hobby farms, natural habitats, sanitary facilities, water storage and conveyance systems and septic systems.



Figure 19. 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.

Growers are expected to assess topography, prevailing winds, 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 designed to reduce the risk of contamination from pathogens associated with livestock and wildlife. These zones act as physical separations that limit 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 microorganisms, 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 or pathogens, allowing timely interventions before leafy vegetables are exposed. By incorporating appropriately designed buffer zones, growers add an essential layer of protection that complements exclusion fencing, windbreaks, and drainage systems, collectively safeguarding crop integrity and food safety.

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

- For moderate-sized animal 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.
- Very large feedlots with more than 80,000 head are advised to maintain a separation of about 1,609 meters (one mile) 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.
- Low-density grazing lands and domestic animals are recommended to 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 (30 feet), again subject to modification based on local conditions and risk evaluations.

Windbreaks (Figure 20), 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 microorganisms from nearby livestock operations, feedlots, or unmanaged animal areas directly onto crops. High-speed winds increase 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, while exclusion fencing and physical barriers prevent animals from entering production areas (Figure 21), limiting the introduction of pathogens from faeces or direct contact with crops.

Exclusion fencing (Figure 22) is a fundamental strategy for controlling the entry of domestic animals and wildlife into leafy vegetable production areas, thereby reducing the risk of microbial contamination. Well-designed fencing serves as 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 accounting for local wildlife movement patterns. In addition to keeping animals out, exclusion fencing supports other food safety measures by helping define controlled areas for monitoring, facilitating routine inspections, and enabling the implementation of buffer zones. 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 20. Perennial windbreaks consisting of tall hedges reduce the movement of airborne contaminants and contribute to the mitigation of food safety and biosecurity risks.



Figure 21. Fencing is critical for preventing animal intrusion.



Figure 22. Fencing and other physical barriers around water sources are critical to prevent access by livestock, wildlife, and other animals.

Proper drainage systems (Figure 23) are critical for reducing contamination risks associated with run-off and flooding from nearby animal operations. Floodwaters or surface run-off can carry pathogens, manure residues, 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 crop areas and reducing the risk of pathogen transfer. By combining effective drainage with windbreaks and exclusion barriers, growers establish multiple layers of protection that mitigate both airborne and waterborne contamination, ensuring safer leafy vegetables and enhancing overall food safety resilience.

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, 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 drainage management for securing the leafy veg 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*.
- Routinely assessing hazards throughout the crop's life cycle, including at least once within the week before harvest.
- Preharvest pathogen testing is recommended for leafy vegetables grown in proximity to animal operations.



Figure 23. A drainage channel on a farm.



Figure 24. Composting areas should be separated from water sources and protected with suitable barriers to prevent contamination through wind dispersal and run-off.

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 microbial hazards through run-off, leaching, wind dispersal, animal activity, or 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.

Key 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 (Figure 27).
- 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.
- 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 27. Storage of organic amendments in a wheelbarrow adjacent to a polytunnel used for leafy vegetable production on a small farm.





Weather

Extreme weather, which is increasingly driven by climate change, is intensifying both in frequency and severity throughout the globe. These include floods, cyclones, droughts, dust storms, bushfires, and prolonged heatwaves, all of which can have profound effects on horticultural systems. In particular, horticultural production and postharvest operations are highly vulnerable, as these can disrupt planting schedules, damage crops, reduce yields, and compromise storage and transportation conditions. While the direct effects of such extreme weather on crop losses are widely recognised, the broader implications for microbial food safety, especially in the fresh horticultural produce sector, remain comparatively underexplored. Extreme weather is known to exacerbate microbiological contamination risks in fresh produce, considering both pre- and postharvest stages.

Flooding

Flooding is the most frequent natural disaster affecting the leafy vegetable industry. Floodwaters 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* 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 postharvest facilities.

Floodwater might carry physical hazards (wood, metal, glass), chemical contaminants (residues, heavy metals, toxins), and biological hazards (bacteria, viruses, parasites) into the food production system (Figure 28). 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. Pathogens, including *Salmonella*, STEC, and *L. monocytogenes*, were detected in lettuce, soil, and irrigation water shortly after flooding, although bacterial populations declined significantly after three 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, taking into account pathogen die-off rates, temperature, soil type, and crop characteristics. Prefer 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 conduct regular monitoring of water and environmental conditions as integral components of a comprehensive food safety strategy.

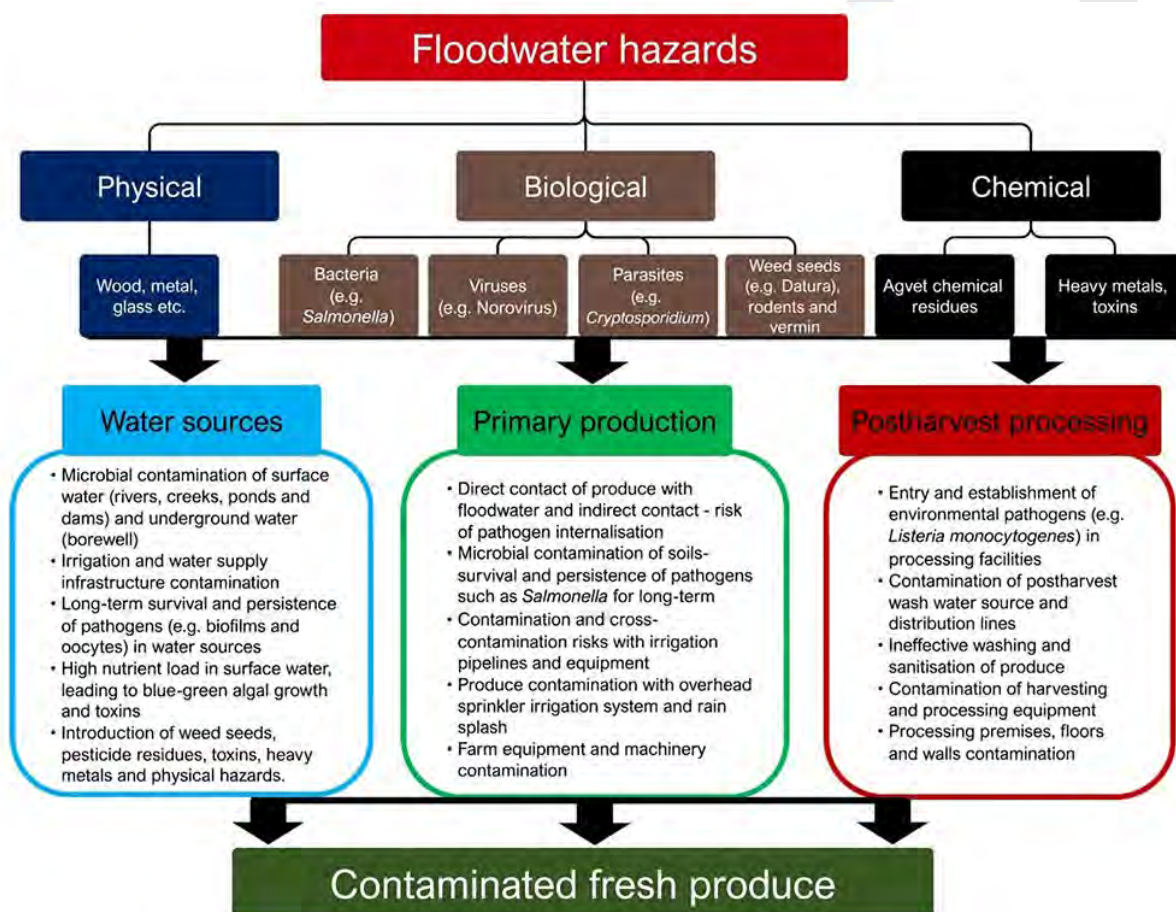


Figure 28. Floodwater as a source and route of microbial contamination in fresh horticultural produce adjacent to livestock, industrial and residential areas.

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 through splash and transfer of microorganisms from 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 through the movement of harvesting machinery across wet fields ([Figure 29](#)).



Figure 29. Conducting agronomic operations in wet conditions can generate mud splash 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, medium 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 30](#)). Attention should also be given to the cleanliness and hygiene of harvesting equipment and machinery. Furthermore, postharvest washing and processing procedures should be reviewed and adjusted, where necessary, to compensate for the increased organic and microbial load associated with produce harvested after moderate and 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 field conditions to dry adequately.
- Inspect crops for visible soil contamination and excess moisture.
- Thoroughly clean and sanitise harvesting equipment and machinery before use.
- Remove accumulated 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 31](#)).

- Review and adjust postharvest 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 events 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 30. Harvesting in wet conditions can result in increased soil contamination of machinery and produce, increasing food safety risks.



Figure 31. 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, feral pigs, deer, rodents, and marsupials, into agricultural areas in search of food, water, and shelter. Their presence in fresh produce fields not only damages crops but also introduces microbial 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 species of animal 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 through harvesting, washing, and postharvest handling, ultimately posing a risk to consumers. Agricultural water sources such as ponds and dams can act as ongoing reservoirs of pathogens if defaecated near or in by wildlife, while postharvest operations, including wash water, equipment, and processing facilities, can facilitate further spread.

Bushfires risk management strategies

- Mitigating microbial risks requires proactive measures, including regular field monitoring, preharvest inspections, and establishing buffer zones around contaminated areas.
- Physical barriers such as fencing or netting can reduce wildlife access to crops and water sources. Harvest 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 spots with faeces or affected produce, refraining 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 1.52 m (5 feet) radius of buffer zone for leafy greens.
- Contaminated harvest bins, equipment, and processing facilities should undergo thorough cleaning and sanitisation, and water and produce should be tested microbiologically as needed.
- A co-management approach is recommended, balancing wildlife and environmental conservation with measures to minimise microbial hazards, ensuring the safety and quality of fresh produce while maintaining ecological stewardship.





Premises and equipment

Premises

Packing sheds and processing facilities shall be designed, constructed and maintained to minimise the risk of contamination of leafy vegetables from 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, wastewater 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 the attraction of pests. Premises should be adequately fenced and managed to prevent the entry of livestock, wildlife and reptiles, as these animals can serve as reservoirs and vectors of microbial contaminants, including foodborne pathogens. Buildings should be designed to facilitate hygienic operations, including adequate separation between raw product handling areas, washing and processing operations, finished product storage and waste handling activities. Traffic patterns for personnel, equipment and product 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 readily cleanable. Floors, walls, ceilings, doors and drainage systems should be maintained in good repair and designed to prevent the accumulation of dirt, moisture and organic matter. Adequate lighting and ventilation should be provided to support hygienic operations and effective cleaning.

Facilities should be protected from the entry of pests, birds, wildlife and reptiles through appropriate exclusion measures such as fencing, sealed building structures, screened openings and regular maintenance. Findings from the Safe Leafy Veg project demonstrated that microbial pathogens can 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 pathways between the field and facility environment.

While contaminated produce can introduce microorganisms into processing facilities, movement of 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 during 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 where appropriate, and routine cleaning and sanitation of floors and drains.

A documented cleaning, sanitation and maintenance program should be implemented to ensure that all premises remain in a condition that supports the production of safe leafy vegetables.





Equipment

Equipment used for harvesting, cooling, washing, processing, packing, storage and transportation of leafy vegetables shall be designed, installed and maintained to prevent contamination of produce. Produce-contact surfaces should be constructed from non-toxic, corrosion-resistant materials and designed to allow effective cleaning, inspection and sanitation (Figure 32). Equipment should be free from cracks, corrosion, damaged surfaces and other defects that might harbour microorganisms or impede cleaning. Preventive maintenance programs should be implemented to ensure equipment remains in a hygienic operating condition and does not become a source of contamination.



Figure 32. Produce contact surfaces, such as conveyor belts, should ideally be smooth and be maintained in a clean and sanitised condition.

Harvesting operations involve the use of a wide range of tools, equipment and containers that come into direct contact with leafy vegetables and therefore have the potential to act as 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 through 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 demonstrating that pathogen transfer is more likely when soil is wet following rainfall, irrigation or flooding. Under these conditions, 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 33) 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 product.



Figure 33. Produce contact surfaces such as harvest 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 sanitation of produce-contact surfaces and adjacent areas, with particular attention given to harvest knives, conveyor belts, harvest bins and other equipment that frequently contact produce. Cleaning should focus on the effective removal of soil and organic matter before sanitiser application, as organic residues can significantly reduce sanitiser efficacy and protect microorganisms from inactivation. Written sanitation standard operating procedures should clearly describe cleaning frequencies, methods, chemicals, equipment disassembly requirements where applicable, and verification activities.

Particular attention should also be given to equipment used in washing and processing operations, including flumes, wash tanks, conveyors, spray systems, centrifuges and packing lines. These systems should be routinely cleaned and sanitised to prevent the development

of biofilms and the accumulation of organic matter that might facilitate pathogen survival and cross-contamination. Conveyor belts require special consideration because belt joints, rollers, bearings and inaccessible surfaces can provide harbourage sites for microorganisms. 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 cleanability, prevention of contamination combined with robust cleaning and sanitation programs remains the most effective strategy for minimising microbial risks associated with harvesting and processing equipment.



Figure 34. Environmental swabbing of harvesting equipment to verify the effectiveness of cleaning and sanitisation.

The Safe Leafy Veg project team found foodborne pathogens on both field equipment and within packing and processing facilities; however, pathogen detections were generally more frequent within packing and processing facilities than on field equipment. These findings demonstrate that packing sheds and processing facilities can act as important 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 identified as common locations for pathogen detections, highlighting the importance of effective sanitation programs and environmental monitoring. The movement of machinery, harvest aids and bins from production fields into packing and processing facilities can contribute to the transfer of soil, organic matter and associated microorganisms, particularly in production regions with heavy clay soil and during wet weather conditions.

Cleaning and sanitisation

Cleaning and sanitisation are distinct but complementary processes. Cleaning involves the removal of soil, plant debris, organic matter and other contaminants (Figure 35) through 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 demonstrated 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 have been shown to 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 35. Removal of plant debris and organic matter from processing equipment during cleaning is essential to ensure effective sanitisation and reduce the risk of microbial contamination.

The effectiveness of sanitation 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, plastics, 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 might 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. Regular validation and verification of cleaning and sanitation procedures through inspections, 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 at the completion of each harvesting shift and whenever contamination is suspected (Figure 36).
- Produce-contact surfaces on harvesting equipment, including conveyor belts and harvesting knives, should be routinely inspected, cleaned and sanitised to prevent the accumulation of soil, plant residues and microbial contaminants.
- Conveyor belts and harvesting knives can support the formation of microbial biofilms if organic matter is allowed to accumulate. Effective cleaning procedures should therefore focus on the complete removal of soil and plant debris before sanitiser application.

- Harvest bins, crates (Figure 37) and other produce containers have been identified as major hotspots for cross-contamination. They should be cleaned and sanitised (Figure 38) after each use and before being returned to the field for harvest operations.



Figure 36. Deep cleaning and sanitisation of all parts of harvesting equipment, including hard-to-reach niches, are critical to reducing contamination risks.



Figure 37. Harvest crates and other produce containers are major hotspots for cross-contamination.



Figure 38. An automated unit for cleaning and sanitising harvest crates.



Figure 39. A project team member collecting microbiological swabs from plastic crates.

- Cutting knives, trimming knives and chopping equipment used during field harvesting or within 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 microorganisms and impede effective cleaning.
- Harvesting machinery operating under wet field conditions 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 sanitation programs should be verified through documented inspections and, where appropriate, ATP monitoring, environmental swabbing or microbiological testing.
- Vacuum cooling systems should be included within the facility's documented cleaning and sanitation program. Vacuum chambers and associated equipment should be routinely cleaned and sanitised to prevent the accumulation and spread of microbial contaminants.
- Water, if used in hydro-vacuum cooling systems, should be of drinking water quality and contain less than 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 the accumulation of organic matter, biofilms and microbial contaminants.
- 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 minimise the establishment and persistence of environmental pathogens. Particular attention should be given to floors, drains, evaporator units, cooling coils, condensate drip trays, walls, doors and other areas prone to moisture accumulation.
- Environmental pathogens such as *Listeria monocytogenes* can survive and persist under 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.





Temperature of harvested leafy vegetables

Temperature management is one of the most important postharvest practices for maintaining the safety, quality and shelf life of leafy vegetables. Following 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 microorganisms and, where conditions permit, human pathogens. Rapid removal of field heat and maintenance of the cool chain are therefore essential to minimise microbial risks and preserve product quality.

Vacuum cooling is the most widely used cooling method in the leafy vegetable industry because it efficiently removes field heat from large volumes of product within a short period (Figure 40). However, many small and medium-sized leafy vegetable businesses do not have access to vacuum cooling facilities due to cost and infrastructure limitations. In these situations, alternative cooling methods and good temperature management practices become even more important to ensure produce is cooled as quickly as possible after harvest (Figure 41).



Figure 40. Vacuum cooling is the most common precooling method in the leafy vegetable industry.



Figure 41. Cold storage facility used for cooling of harvested produce on a small-scale farm.

- Harvest leafy vegetables during the coolest periods of the day and minimise the time between harvest and cooling. Harvested produce should be protected from direct sunlight using shade cloth, covered trailers or other suitable methods while awaiting transport or processing.
- 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 implemented to achieve rapid temperature reduction.
- Water used for hydro-cooling or vacuum cooling should be of drinking-water quality and routinely monitored to ensure it does not become a source of microbial contamination.
- Maintain cool chain throughout washing, processing, packing, storage, transport and distribution (Figure 42).
- 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 42. The cold chain (2–4 °C) should be maintained during all postharvest stages to minimise food safety risks.



Figure 43. Produce should not be left out in the sun.





Washing and sanitisation of harvested leafy vegetables

Washing and sanitisation 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 postharvest handling. If poorly managed, wash water can become a vehicle for spreading contamination from contaminated produce to uncontaminated produce. The addition of sanitisers to wash water is essential for controlling microbial contamination and minimising cross-contamination during processing. Sanitisers are primarily intended to inactivate microorganisms in the wash water rather than to sanitise the leafy vegetables themselves. In addition to wash water sanitisation, 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 safe leafy veg showed that triple washing was more effective in reducing microbial load on spinach and rocket leaves compared to double washing.
- A pre-wash rinse is an important first step in leafy vegetable processing and is designed to remove the majority of 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 sanitisation systems, reduces water and sanitiser demand, and minimises cross-contamination risks.
- Water used for washing and sanitising leafy vegetables should be of drinking-water quality and contain less than 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 44](#)).



Figure 44. Postharvest 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 microorganisms during processing.
- Sanitiser concentrations and contact times should be maintained at validated levels throughout processing.
- Industrial-scale studies have shown that 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 demonstrated 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. 2019; Tudela et al. 2019).
- Peracetic acid (PAA) is commonly used in leafy vegetable processing because it remains effective in a broad pH range and under 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. Continuous monitoring of free chlorine or peracetic acid concentrations, pH, oxidation-reduction potential (ORP), temperature and water turbidity can help ensure that 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 the majority of dirt and organic material before produce enters 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 result in the rapid accumulation of soil, plant debris, leaf exudates and microorganisms 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 45).



Figure 45. Adequate water-to-produce ratios during washing help maintain wash water quality and reduce the risk of microbial cross-contamination.

- Wash water replenishment should be undertaken continuously or at defined intervals to maintain process water quality and prevent the accumulation of soil, plant debris, organic matter and microorganisms. Water replacement rates should be based on product throughput, organic loading, turbidity, sanitiser demand and microbial risk.



Figure 46. Effective cleaning is essential for removing soil, organic matter, and plant debris prior to sanitisation, ensuring the efficacy of sanitisers and reducing the risk of microbial contamination.



Figure 47. Accumulation of residual soil and organic matter at the bottom of a wash-water tank following the harvest of baby spinach after heavy rainfall.



Figure 48. Washing and sanitisation of harvested herbs by immersion in crates, illustrating both the washing process and the diversity of leafy vegetable crops.



Figure 49. 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 Shiga toxin-producing *Escherichia coli* (STEC), *Salmonella* spp. and *Listeria monocytogenes*. Effective management of animals and pests is therefore essential to minimise contamination risks and protect the safety of leafy vegetables.

- Regularly assess the risks associated with animals and pests in production fields, water sources, buildings, equipment and surrounding areas.
- Conduct routine inspections 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 the entry and establishment of animals and pests through the use of 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.
- Monitor crops regularly for animal intrusion, with particular attention immediately before harvest when contamination is most likely to affect product safety.
- Where evidence of significant 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 where the next crop is intended to be planted within a short period. Grazing animals can deposit faeces directly onto the soil surface, introducing foodborne pathogens.
- Where grazing has occurred, an appropriate waiting 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 sources of contamination 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 in conjunction 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 winds, 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 50).
- Ensure buildings, packing sheds, cool rooms and processing facilities are designed and maintained to prevent the entry of birds, rodents, insects and other pests 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 50. Water birds on a farm pond.



Figure 51. Waterbird activity around an irrigation dam, showing faecal contamination on the dam liner as a potential source of microbial hazards.

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Skills and knowledge

Personnel involved in the production, harvesting, packing, processing, storage and transport of leafy vegetables should possess food safety and food hygiene knowledge and skills that are 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. 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 assist in identifying 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, contamination prevention, equipment sanitation, water management, pest control, product handling and reporting of 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 training programs, mentoring by experienced staff, formal training 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, 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 communications as part of the food safety management system.



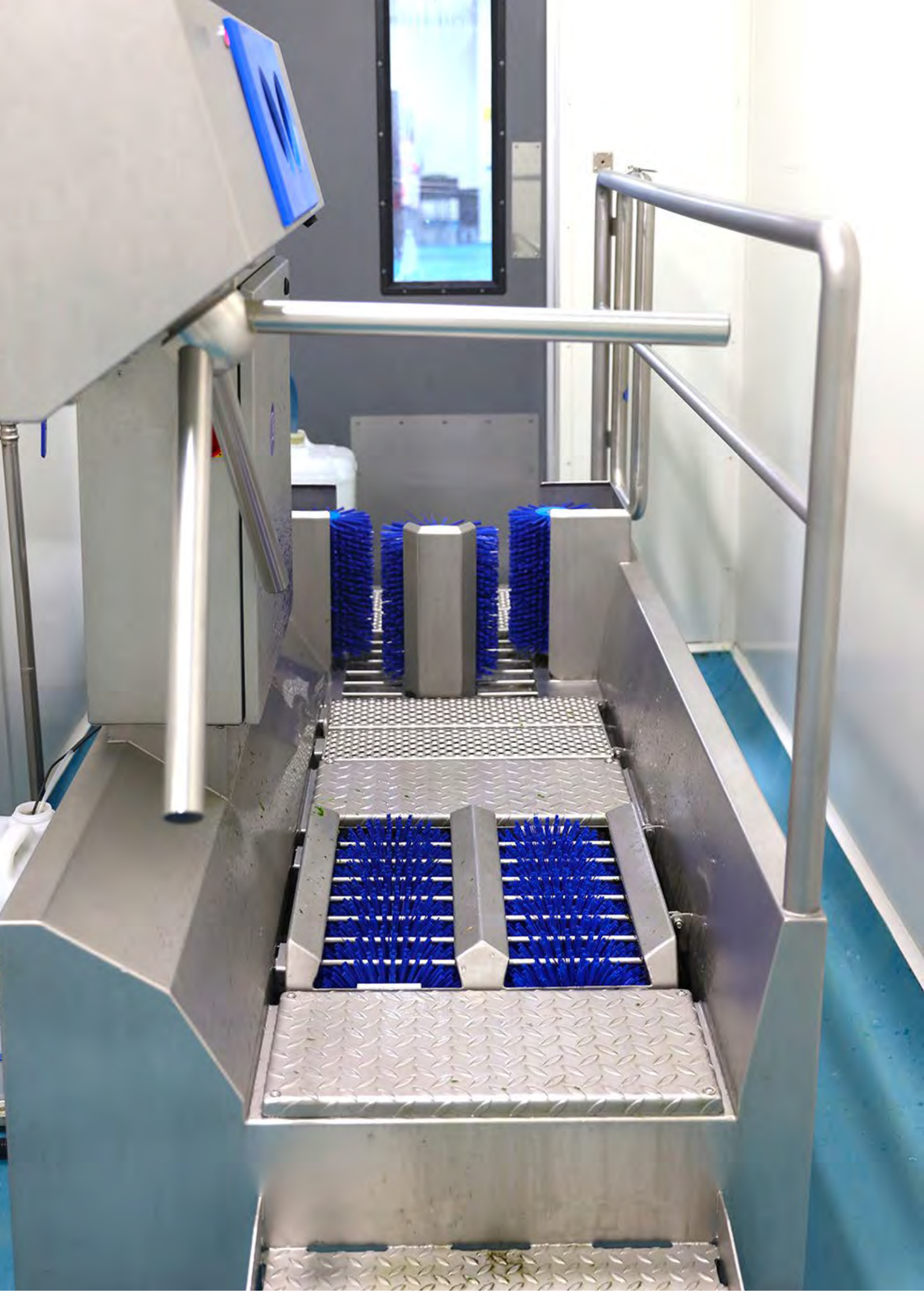
Figure 52. Pre-harvest inspection to identify and assess potential food safety hazards, including toxic weeds, wildlife intrusion, animal activity, and other sources of contamination.



Figure 53. Having trained personnel during mechanical harvesting of baby leaf vegetables to monitor and manage potential food safety hazards introduced during harvest operations.



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 protect product safety.





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 also 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 commencing work, after using the toilet, after eating, drinking or smoking, after handling contaminated materials, after 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 who are suffering from symptoms of 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, where appropriate, suitable protective garments such as gloves, aprons, hair coverings, beard covers, face masks and protective footwear (F). 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 where necessary.
- 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 under conditions that ensure 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, that the product is unsafe or unsuitable for human consumption.

Unacceptable leafy vegetables include produce that might present 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 product to prevent it from entering the food supply chain.

Examples of unacceptable leafy vegetables

- Leafy vegetables that have been directly contacted or submerged by floodwaters, where the edible portions have been exposed to potentially contaminated water.
- Leafy vegetables contaminated by fuels, lubricants, pesticides, cleaning chemicals or other hazardous substances as a result of spills, leaks or accidental exposure.
- Packaged leafy vegetables containing visible soil, mud, insects, spiders, frogs, animal faeces or other foreign material that indicates inadequate cleaning or contamination.
- Leafy vegetables affected by significant animal intrusion, faecal contamination or carcasses where food safety cannot be assured.
- Leafy vegetables that have been exposed to contaminated water, untreated waste, sewage or other sources of microbiological contamination.
- Leafy vegetables that have deteriorated due to poor temperature control, excessive spoilage, decay or decomposition and are no longer suitable for human consumption.
- Product associated with a food safety incident, microbiological test result, 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.
- Implement monitoring and verification activities throughout production and processing to identify unacceptable product before it enters the market.
- Establish procedures for the segregation, identification and disposition of produce that might be unsafe or unsuitable.
- Investigate contamination, equipment failures, water quality issues, temperature deviations or other incidents that might affect product safety.

- Maintain 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 a product, adopt a precautionary approach and withhold the product from sale until its acceptability can be determined.

DRAFT



Shiga toxin-producing *Escherichia coli* (STEC) 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 toxins known as 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 like 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 characterised by Shiga toxin (Stx) production. 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 (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 and the annual rate of cases (1.99 cases per 100,000 per year) increased significantly during this period (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 contrast, 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 in their ability to 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:

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 like 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 55), particularly closer 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.



Figure 55. Applying contaminated surface irrigation water with an overhead irrigation system elevates the risk of leafy vegetables contamination.

3. **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 through direct contact with soil or indirect splashing with rain and overhead irrigation.
4. **Growing site:** the coexistence 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.
5. **Harvesting:** if workers or harvesting equipment come into contact with 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.
6. **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 postharvest processing.
7. **Postharvest 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 56).
8. **Extreme weather conditions:** heavy rainfall that results in run-off or flooding (Figure 57), dust storms, bushfires and heatwaves affect fresh produce safety (Singh 2023). Natural disasters often exacerbate the transfer of microbial pathogens from the environment into production fields, water sources and postharvest processing facilities.



Figure 56. The wash water must have appropriate sanitiser concentrations.



Figure 57. Extreme weather conditions, such as heavy rainfall, can transfer microbial pathogens from the environment into production fields, water sources and postharvest 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:

Preharvest water quality management: irrigation water from surface sources such as rivers and canals should be pumped and stored in a dam/pond to allow the suspended solids to settle. The presence of 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 58).

Irrigation water quality should be monitored regularly (Figure 59), 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 58. Using coarse filtration and frequent backflushing minimises the sediment and reduces the microbial population in irrigation water.

Organic soil amendments: composts containing animal manure should be free from harmful pathogens (Figure 60). Commercial products must be treated in accordance with the [Australian Standard AS4454-2012 Composts, soil conditioners and mulches](#). Traceability of composts containing animal products (e.g. source, batch, certification) sourced and applied in the production system is important to take corrective actions if required.

Coexistence 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. Cattle, in particular, are considered one of the highest-risk animals for STEC contamination. Extreme weather conditions (e.g. dust storms, heavy rainfall, cyclones) influence the transmission and spread of contamination within the broader environment surrounding cattle operations. Proper drainage systems should be installed to curtail run-off risk from neighbouring animal operations.



Figure 59. Collecting samples to test irrigation water.



Figure 60. Microbiological sampling of compost samples.

Harvest and postharvest management

- Harvest equipment hygiene is crucial for managing cross-contamination risks.
- Rapid pre-cooling and maintaining a cool chain ($<5^{\circ}\text{C}$) 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 postharvest 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 leafy processing should have an appropriate sanitiser concentration in each washing and sanitising tank (Figure 61).
- 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 in the event of an outbreak or product recall. Proper documentation of each stage of the supply chain is essential for efficient trace-back procedures. Growers should maintain records of all farm inputs such as soil amendments, fertilisers and water used for leafy vegetable production and processing.



Figure 61. Appropriate sanitiser concentrations should be in each washing and sanitising tank.



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.

A recent foodborne illness intoxication outbreak linked to fresh baby spinach contaminated with the toxic weed thornapple (*Datura stramonium*) is an example of a food safety risk that growers and other supply chain participants may not be familiar with.

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; [Figure 62](#) to [Figure 65](#)). This weed was found in product 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. (thornapples, jimsonweed), *Atropa belladonna* (deadly nightshade) and *Hyoscyamus niger* (common henbane) are known to be toxic due to the accumulation of tropane alkaloids (TA) in their leaves, stems, flowers and fruits. TA are the secondary plant metabolites that are distributed in many other species of the genera such as *Solanum*, *Mandragora*, *Brugmansia*, *Duboisia*, and *Scopolia*.

Although over 200 TA 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 62. *Datura stramonium* foliage. Photo: Bruce Ackley, The Ohio State University, Bugwood.org.



Figure 63. *Datura stramonium* foliage. Photo: Lynn Sosnoskie, University of Georgia, Bugwood.org.



Figure 64. *Datura stramonium* flower. Photo: Lynn Sosnoskie, University of Georgia, Bugwood.org.



Figure 65. *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 jimsonweed 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 2019, 108 people were hospitalised in Turkey after ingesting spinach suspected to be contaminated with TA (ProMED-mail, 2020).
- In July 2020, a family in France mistakenly cooked and consumed jimsonweed 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 the fact that *Datura stramonium* grew 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 undertakes 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. There are several factors that 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 growers' ability to undertake effective weed control
- there are limited pre-emergent and post-emergent herbicide options to manage a variety of weeds
- post-emergent selective herbicides could be unable to cover the entire weed spectrum
- herbicide application and efficacy could be affected by rainfall and other factors
- 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 (less) planting density can provide more space for weeds to grow and compete with the crop
- excessive rainfall during the early stages of planting and growth could decrease the efficacy of pre-emergent as well as post-emergent herbicides
- toxic weeds at early growth stages (leaves and stem) 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 field 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-emergent and post-emergent herbicides capable of targeting toxic weeds should be part of the weed control strategy
- 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 in identifying problematic toxic weeds and reporting to the harvest crew manager or supervisor
- processors should train and educate workers to report any unusual weeds/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.





Microbiological testing

Microbiological testing is an important verification tool that can assist growers and processors in assessing the effectiveness of food safety controls and identifying potential sources of contamination. Testing might be undertaken on produce, water, soil and environmental samples 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)
- are grown in soil amended with untreated or partially treated animal manure
- have been exposed to extreme weather such as flooding, heavy rainfall, dust storms or cyclones
- are produced near livestock operations or other potential sources of faecal contamination
- are grown on land where livestock grazing has occurred before planting
- are associated with a food safety incident, product complaint, pathogen detection or recall investigation.



Figure 66. Collection of representative produce samples using appropriate hygiene practices, including the use of disposable gloves to minimise the risk of sample contamination.

Preharvest produce testing

Modelling conducted by Reyes et al. (2023) demonstrated that product testing is most effective when undertaken before postharvest interventions such as washing and sanitisation, as contamination in the field might be diluted or masked by subsequent processing steps. Preharvest testing, therefore, provides growers with an opportunity to identify potential food safety risks before harvest and make informed decisions regarding crop disposition (). However, preharvest 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 67. Pre-harvest testing enables growers to identify potential food safety risks before harvest and make informed decisions regarding harvest timing and product use.

Routine preharvest 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 flooding, cyclones, severe weather, animal intrusion, irrigation water quality failures, food safety incidents, pathogen detections, product recalls or outbreak investigations. Growers seeking to implement preharvest 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.

Preharvest 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 preharvest sampling plan adapted from the California Leafy Greens Marketing Agreement (LGMA) is provided in Table 1.

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, four 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 maximise representativeness. Each sub-sample should be submitted and analysed as a separate test unit.

Laboratories undertaking 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.

Natural disasters and flood-affected crops

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

Where flooding has occurred, growers should undertake a documented risk assessment before replanting. Consistent with 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 supported by microbiological testing demonstrates 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 preharvest testing

- Conduct preharvest sampling as close as practical to harvest, preferably within seven days of the planned harvest date.
- Consider defining sampling units as lots of one acre (0.4 hectares) 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), *Salmonella* spp. and *Listeria monocytogenes*. 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 product disposition decisions.

Soil testing

Soil testing should be considered where production fields:

- have been affected by flooding or other extreme weather that might introduce contaminants
- have received 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.

- Boot swab sampling involves placing sterile absorbent covers over boots and walking through the field ([Figure 68](#)) so that soil and any microorganisms on the soil surface are collected over a large area.



Figure 68. A soil boot swab by a farm staff member.

- 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.
- 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 aggregative methods that cover larger areas and are useful for detecting surface contamination, soil grab samples provide information about the conditions and potential contamination present within 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 sanitation effectiveness. Bootie swabs allow the collection of surface-level samples over a larger area as the sampler walks through the environment. Recent studies have demonstrated the potential of bootie swab sampling as a preharvest produce safety tool, showing that aggregate bootie 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.

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 in comparison to conventional soil grabs (Kealey et al. 2026). However, bootie swabs might have limitations under very moist or wet soil conditions, 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 under suitable field conditions.

Soil testing can be a valuable verification tool where elevated contamination risks have been identified, particularly following flooding, the application of 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 acre of production area, a minimum of four sampling locations should be selected to ensure representative coverage of the field. At each location, one boot swab sample is collected by aseptically 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 four boot swab samples per acre.
- One composite soil grab sample might be collected from four sampling locations per acre using a soil probe or scoop to a depth of 10–15 cm. Each composite soil sample should consist of at least three 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 the 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 where appropriate.
- Additional sampling can be conducted from primary water sources such as rivers/canals/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 cooled immediately after collection, and laboratory analysis conducted promptly (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 [Figure 69](#), dams 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.



Figure 69. Livestock activity upstream may compromise the microbial quality of irrigation water sources.

Growers should review and analyse historical water quality data, ideally over a period of 5–10 years where available, to identify seasonal trends, spikes and declines in *E. coli* populations and other indicators of contamination. Understanding these patterns can assist growers in identifying periods of elevated risk, assessing the effectiveness of mitigation measures and developing 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.

As a general guide, large-scale growers (>10 hectares) should test irrigation water monthly during crop production periods. Medium-scale growers (2–10 hectares) should undertake seasonal testing, with a minimum of four samples collected annually or at least one sample during each production season. Small-scale growers (<2 hectares) should test irrigation water at least annually during crop production and preferably during periods of greatest risk, such as the summer months (December–January). Businesses using higher-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, product recalls or significant changes in production practices.
- Investigate and document positive pathogen detections or elevated indicator organism results and implement corrective actions where necessary.
- Review testing data over time to identify trends, emerging risks and opportunities for continuous improvement in food safety management.

Postharvest water testing

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

- Conduct microbiological testing of water used for produce washing, 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.

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Appendix I

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

State/Territory	Agency	Contact details	Enquiry Type
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.
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.
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 & Regulation	Phone: (08) 8429 0837 Email: pirsa.foodsafety@sa.gov.au Website: www.pir.sa.gov.au	Primary production, food safety and horticulture
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.
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
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.
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.

* 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, postharvest 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 growers 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. Growers 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 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)
- ☐ Soilless production (e.g. hydroponic) in open environment
- ☐ Soilless production (e.g. hydroponic) under cover (partially enclosed structures)
- ☐ Soilless 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 Postharvest activities

- ☐ Field packing
- ☐ Trimming and cutting
- ☐ Washing
- ☐ Washing and sanitising
- ☐ Cooling
- ☐ Cold storage
- ☐ Packing
- ☐ Repacking
- ☐ Storage
- ☐ Distribution
- ☐ Transport
- ☐ Other postharvest 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 product 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 Product 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 Product recall

Does your business have a documented product 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)

☐ Postharvest 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)
- ☐ Before each crop cycle
- ☐ Following significant rainfall or flooding
- ☐ No testing conducted
- ☐ No testing 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
- ☐ 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 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 postharvest 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.

- ☐ Product 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?

- ☐ Product 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 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 microbiological 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 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 postharvest equipment for potential contamination risks?

- ☐ Yes
- ☐ No

Identify 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 sanitisation 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 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 postharvest 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: _____

Postharvest equipment cleaning and sanitisation 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 sanitisation 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 product 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 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, product 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
- ☐ Product traceability and recall procedures
- ☐ Identification and management of unacceptable product
- ☐ 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 product

10.1. How do you identify an unacceptable product?

☐ 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 product 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

DRAFT



Safe Leafy Veg



Best practice guidance



Flooding adversely affects fresh produce safety

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ABSTRACT

Flooding is the most recurring and common natural disaster affecting society, food security and the environment. Floodwater is known to be a carrier of biological, chemical and physical hazards affecting food safety during primary production and processing of fresh horticultural produce. Runoff from livestock, industrial, residential and sewage treatment areas into waterways and their overflow can contaminate agricultural water sources, production fields and post-harvest processing facilities. A transient increase in the population of faecal indicators such as *Escherichia coli* and the detection of environmental pathogens such as *Listeria monocytogenes* and *Salmonella* in produce, water, soil and processing facility are the short-term and most notable impacts of flooding, leading to a significant amount of food losses due to microbial contamination and potentially a rise in the foodborne illnesses among produce consumers. However, the long-term impacts of recurring flooding are far more severe and damaging due to the survival and persistence of microbial pathogens in soils, water sources and processing environments. This article focuses on how flooding can exacerbate the microbial food safety risks in the primary production and processing of fresh produce and briefly describes the management strategies.

Keywords: floodwater, foodborne pathogens, food safety, fresh produce, irrigation, natural disaster, post-harvest processing, soil and water contamination.

Flooding events have been a recurring natural disaster in Australia, causing significant economic damage to infrastructure, communities and the environment. With a reduction in average annual rainfall, the intensity and frequency of heavy rainfall in Australia is predicted to increase, leading to extreme weather events such as floods, cyclones, drought and temperature extremes.¹ In 2022, 47 flooding events were declared natural disasters as per the Australian disaster database (Australian Government Department of Home Affairs, see <https://www.disasterassist.gov.au/find-a-disaster/australian-disasters>, accessed 19 August 2023). The total costs of natural disasters in Australia in 2017 were estimated to be A\$18 billion per year and forecasted to rise to \$39 billion per year by 2050.² Flooding has been the most damaging natural disaster costing on an average \$8.8 billion per year, which is approximately half the total costs of all natural disasters such as cyclone, hail, storm and bushfires. In addition to direct economic losses, flooding events can have significant effects on the food security and the occurrence and spread of foodborne diseases in the communities, whose economic impacts are currently unknown.

Extreme weather events such as flooding have been linked with foodborne and waterborne gastrointestinal illness outbreaks.³ Fresh horticultural produce, generally grown in open fields, is more prone to extreme weather events, natural disasters and associated food safety risks. In Australia, dust storms were associated with *Listeria monocytogenes* outbreak caused by rockmelons in 2018. Similarly, flooding or runoff was speculated to be responsible for introducing toxic weed (*Datura stramonium*) seeds into spinach production field, leading to a large-scale intoxication outbreak in December 2022 caused by the contamination of bagged spinach leaves with weed leaves.⁴ The increase in foodborne illness outbreaks related to fresh produce is a global concern with frequent implications of microbial contaminants such as Shiga-toxin *Escherichia coli* (STEC), *Salmonella* species and *L. monocytogenes* in these outbreaks. Natural disasters such as flooding can aggravate the distribution and transmission of microbial contaminants in agricultural production and processing systems.

Flooding events and associated hazards

Flooding can be broadly categorised into two types. The first type is linked to heavy rainfall leading to water accumulation in production fields and can affect microbial

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contamination of fresh produce through overland flows and splash transfer of pathogens from the soil onto the crops during rainfall.⁵ In Finland, a *Cryptosporidium parvum* outbreak in 2012 was speculated to be caused by contaminated water splash from heavy rains onto frisee salad in the fields.⁶ An increase in the detection of foodborne bacterial pathogens on fresh produce has been observed after heavy rainfall events in Australia (S. P. Singh, unpubl. data).

The second type of flooding, which is experienced as a natural disaster, is severe and involves large runoff and overflow from surface waters such as rivers, creeks, lakes and dams and enters into production fields and post-harvest processing facilities.⁷ Floodwater can carry physical (e.g. wood, metal and glass), chemical (e.g. chemical residues, heavy metals, toxins, petroleum products) and biological (e.g. bacteria, viruses and parasites) hazards and transfer them into water sources, production fields and processing facilities (Fig. 1). The risks of contamination associated with flooding are significant when these operations are adjacent to livestock, industrial and residential areas. Floodwater mobilises pathogens from the environment such as sewage or septic overflow, runoff from livestock operations and compost yards, and industrial areas.

Flooding-induced microbial contamination during primary production and processing of fresh produce

The contamination of water sources poses a serious threat to the introduction and transmission of foodborne illness causing pathogens.⁸ Agricultural water has been implicated in several foodborne illness outbreaks related to fresh produce, including *E. coli* O157:H7 outbreaks linked to romaine lettuce,⁹ enterohemorrhagic *E. coli* in salad¹⁰ and *Salmonella* Newport in tomatoes.¹¹ Floodwater carrying foodborne bacterial and viral pathogens and parasites can introduce these contaminants in water sources, growing crops, soils and processing facilities. The contamination of water sources, both surface and underground, can have short-term and long-term impacts on the pathogen transmission and persistence in the agricultural production and processing environments.⁷

Studies have shown that high faecal indicator pathogen loads are often detected in floodwater¹² and can contaminate agricultural water used for irrigation, foliar sprays and post-harvest operations.⁸ Under normal circumstances, microbial quality of surface water varies considerably according to the season and location. For example, the *E. coli* population in the Australian Murray River water

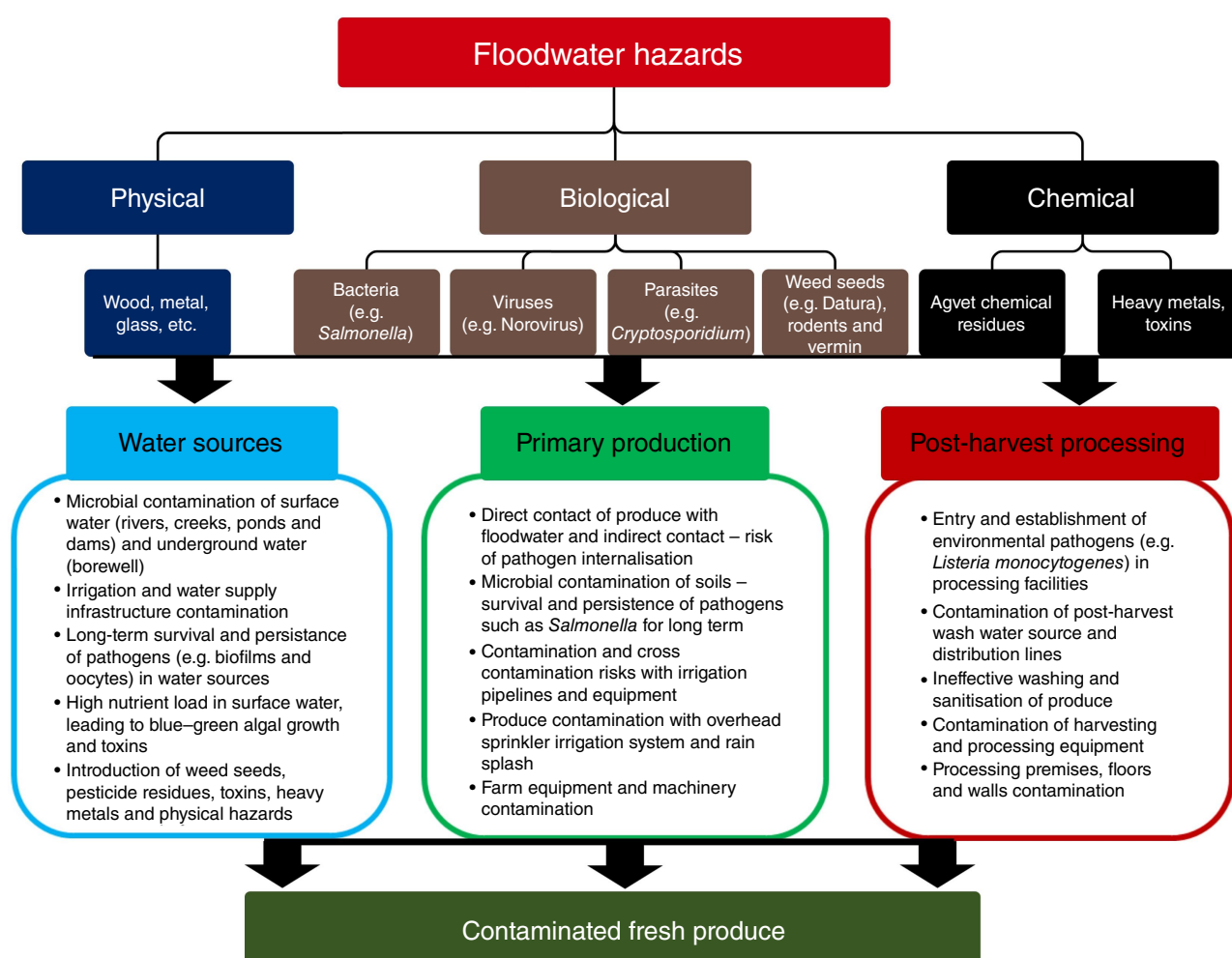


Fig. 1. Floodwater as a source and route of microbial contamination in fresh horticultural produce adjacent to livestock, industrial and residential areas.

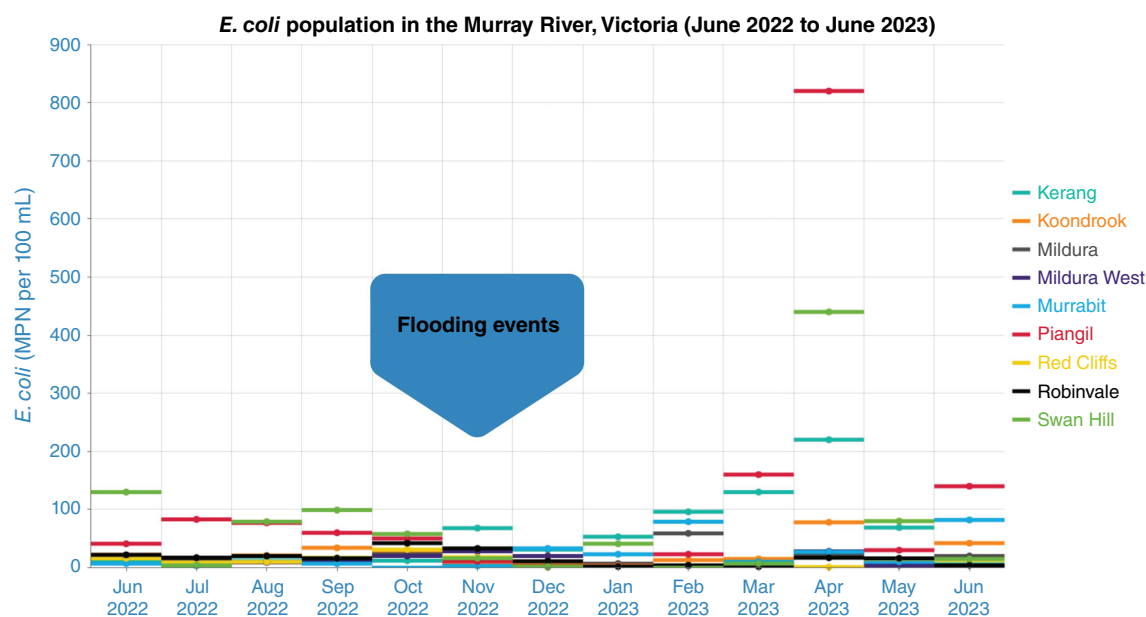


Fig. 2. *Escherichia coli* population in the Murray River water samples collected from multiple locations between June 2022 and June 2023 (Data source: Lower Murray Water, Victoria, Australia, see <https://www.lmw.vic.gov.au/water-supply-and-services/water-quality-and-treatment/e-coli-river-water-reports/>). The flooding events occurred between October and December 2022. MPN, most probable number.

samples collected from multiple locations in the Lower Murray region varied considerably between June 2022 and June 2023 (Fig. 2). The flooding in the region between October 2022 and January 2023 inconsistently increased the *E. coli* population at several locations. The highest *E. coli* population was recorded during April 2023 from Piangil, Kerang and Swan Hill locations, coinciding with the receding of floodwater (Fig. 2).

Microbial pathogens capable of forming biofilms and oocytes can persist in agricultural waters for weeks, increasing likelihood of their transmission.¹³ Further to it, the contamination of agricultural water distribution systems (e.g. pumps, pipelines and sprinklers) can become a source of cross-contamination when water is used for irrigation, foliar application and post-harvest processing. The survival and persistence of these pathogens could be affected by several environmental factors such as solar radiation, organic load, as die off rates of these pathogens are highly variable and influenced by plethora of factors. In addition to microbial risks, high nutrient load in surface water sources (e.g. rivers, lakes and ponds) can also lead to the growth and multiplication of blue-green algae and thus production of associated toxins, making the water unfit for agricultural purposes.¹⁴ These toxins can be absorbed or translocated in the plant system, rendering the fresh produce unsafe for human consumption. Therefore, the impact of flooding on microbial quality of agricultural water can have direct and indirect impacts ranging from short- to long-term.

Floodwater has strong potential to introduce bacterial and viral pathogens and parasites in production field soils. The persistence and survival of these pathogens varies considerably depending upon factors such as temperature, rainfall, solar radiation, soil pH, soil type, moisture, agronomic practices, nutrient availability, as well as soil biological interactions.¹⁵ For example, abundance of the

Salmonella Typhimurium in soils was reduced to the detection limit between 40 and 180 days, most of the *Salmonella* did not survive in soil for more than 90 days. Flooding and soil texture (content of sand) promote the decline rate of *Salmonella* in soils.¹⁵ Similarly, foodborne viral pathogens get readily adsorbed on to fine-textured soils compared to coarse-textured soils. Sandy soils are relatively poor adsorbents of enteric viruses, whereas soils with clay content of 30–100% are excellent adsorbents.¹⁶ The broader understanding and knowledge of die off rates of various microbial contaminants under variable conditions are unknown which limit the scientific basis of advice to growers regarding the post-flooding microbial hazards presents in the soil. Microbiological testing of soil for various target pathogen is thus the most reliable risk assessment method.

Floodwaters can contaminate agricultural equipment, packaging and storage facilities, and transportation vehicles. If these contaminated surfaces come into contact with fresh produce, cross-contamination can occur, leading to the spread of pathogens or chemicals from the floodwaters to the produce. This can happen during harvesting, processing, packing or transportation stages. Environmental pathogens such as *L. monocytogenes* and *Salmonella* can enter the processing facilities with produce itself, workers shoes, equipment and machinery. Contamination of produce-contact (e.g. conveyor belts, brushes) and non-contact surfaces (e.g. floors, walls) can lead to persistent contamination risks if their anchorage and harbourage remains unnoticed.

After a flood event, water used for post-harvest activities, such as washing, rinsing and cooling of fresh produce, can become contaminated. If this contaminated water is used during these processes, it can introduce pathogens or chemicals onto the produce, compromising its safety. Flooding can also lead to a loss of quality and reduced shelf life of fresh produce. Excessive moisture and prolonged exposure

to water can cause physical damage, such as bruising, decay or mould growth, making the produce unsuitable for consumption.

Floodwater impacts on fresh produce safety – case studies

Spain

A study in Spain showed that irrigation water, soil and lettuce samples showed the presence of coliforms and *E. coli* when sampled 1 week after flooding.⁷ However, bacterial population drastically decreased 3 weeks after the flooding. All three major foodborne bacterial pathogens (e.g. *Salmonella*, STEC and *L. monocytogenes*) were detected in lettuce samples after flooding. *Salmonella* was also detected in irrigation water and soil samples 1 week after the flooding. Similarly, another study in a greenhouse grown tomato crop, the presence of *E. coli* and *Salmonella* Newport was demonstrated in tomato samples during and after a flooding event in Mexico.¹⁷

Australia

After October to December 2022 floods in Victoria, a total of 86 samples (18 produce samples and 15 soil drags from production fields and 53 environmental samples from post-harvest processing facility) were collected from a fresh-produce farm located near Mildura, which was partially affected by flooding (S. P. Singh, unpubl. data). STEC was detected in a soil drag sample and on a produce sample from the flood-affected zone of the farm. Similarly, STEC was also detected on harvest bins and drains in the fruit receival area of processing facility, indicating the potential transmission of STEC from soil to produce to harvest bins to drains in the packing facility. *Salmonella* and *L. monocytogenes* were also detected on the non-contact produce surfaces (e.g. floors and drains) of the processing facility. In previous years (2021 and 2022) of food safety monitoring, no foodborne bacterial pathogens were detected on produce and environmental samples collected from this farm (S. P. Singh, unpubl. data). This case study highlights the potential of flooding events in introducing microbial contamination in the production fields and their transmission from field to processing facilities along with produce, harvesting and post-harvest equipment.

Management options

Post-flooding response

Educating growers and farm workers about flood-related risks and appropriate handling practices should be part of the preparedness for natural disasters. The flood-affected zones of the farm should be clearly identified and marked to restrict the potential transfer of microbial pathogens and produce from the affected zone to the clean zone. Once a flooding event has occurred, clear guidelines should be followed such as the United States Food and Drug

Administration (US FDA) guidance on evaluating the safety of flood-affected food crops.¹⁸

Produce that has come in contact with flood water is considered adulterated and cannot be sold for human or animal consumption. If the crop comes in proximity to or is exposed to a lesser degree, a thorough risk-assessment should be conducted involving factors such as the floodwater hazards, type and stage of crop growth, degree and duration of crop exposure to floodwater and related conditions and likelihood for crops to absorb or internalise potential contaminants. Microbiological testing for faecal indicators and foodborne microbial pathogens should be the objective and integral part of food safety risk assessments.

Preharvest water should be subjected to microbial reduction strategies when the microbial load is intermediate (100–1000 colony-forming units per 100 mL). Electrolysis, ozone, UV and photocatalysis hold promise, either as single treatments with pre-treatments that remove suspended material or as combined treatments, with another chemical or physical treatment methods.¹⁹

Flood-affected fields should not be replanted for at least 30–60 days after the water recedes.¹⁸ The waiting period for replanting are based on the known die off rates of pathogens and other factors such as temperature weather and soil type. Replanting with fresh produce crops such as leafy vegetables, herbs, melons and strawberries is not recommended. Crops with edible parts away from the soil and likely to be consumed after cooking or processing are more suitable for replanting.

The US FDA recommends the segregation of flood-affected crops from non-affected crops with a 30-foot (~9.1 m) buffer zone to prevent cross contamination between the flooded and non-flooded fields.¹⁸ Conducting thorough risk assessments of flood-prone areas and implementing appropriate mitigation strategies are important strategies to manage flooding risks. Improving water and flood management systems, such as proper drainage and irrigation practices are critical. Enhancing hygiene practices during harvesting, processing and transportation of fresh produce along with regular testing and monitoring of water sources used in preharvest and post-harvest operation are among the practical management options.

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Data availability. The data that support this study will be shared upon reasonable request to the corresponding author.

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Biography



Dr Sukhvinder Pal (SP) Singh is a Senior Research Scientist at the NSW Department of Primary Industries. His research program is focused on enhancing food safety and traceability in the horticulture sector. His research group studies the sources and routes of microbial contamination in primary production and processing environments of fresh horticultural produce.

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Potential for in-field pre-harvest control of foodborne human pathogens in leafy vegetables: Identification of research gaps and opportunities

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ABSTRACT

Background: Leafy vegetables (LVs) used as raw ingredients in salads have become a crucial part of our healthy diets. However, they are considered to be high-risk foods due to the lack of reliable measures to fully mitigate food safety risks in the absence of cooking prior to consumption. Indeed, outbreaks of foodborne illnesses and recalls associated with LVs continue to occur. This highlights the potential for additional strategies, such as pre-harvest sanitization, to better address the risks.

Scope and approach: This review undertook a comprehensive analysis of the current state of pre-harvest technologies that apply chemical sanitisers via treated irrigation water or via sanitization sprays of the field crop.

Key findings and conclusions: Several potential chemical sanitisers were shown to be effective against various foodborne pathogens when applied pre-harvest to crops. The review identified significant knowledge gaps concerning the efficacy of chemical sanitisers including their effect on the ecosystem health such as plant health, soil health, impacts on the natural leaf and soil microbiome. Addressing these gaps will provide a better understanding of the feasibility of these sanitization methods, including cost-benefit analyses. It is proposed that a risk framework, tailored to specific crops, soil types and weather conditions, should be developed to provide a science-based justification for the implementation of pre-harvest sanitization to improve the safety of LVs.

1. Introduction

Leafy vegetables (LVs) are considered an important component of a healthy diet, providing nutrients that can help prevent chronic diseases (Blekkenhorst et al., 2018). They are often produced ready-to-eat with no, or minimal, processing, and consumed raw. Therefore, with the possible exception of ionising radiation, which has been approved in some countries there are no fully reliable kill steps from sowing to farm gate to prevent transmission of any contaminating pathogens (Gil et al., 2015). Consequently, LVs are considered high-risk foods in terms of food safety to the general public and particularly to immunocompromised people including cancer patients, the elderly, and during pregnancy (Gomez et al., 2023). Internationally there have been numerous outbreaks associated with consumption of LVs. Most of these have been linked to *Salmonella enterica*, pathogenic *Escherichia coli*, Norovirus and *Listeria monocytogenes* (Food Standards Australia New Zealand, FSANZ,

2020; Mogren et al., 2018).

Contamination of LVs with pathogenic microorganisms can occur at any point throughout the production chain from in the field, at harvest, and in post-harvest processing (Rosberg et al., 2021). Moreover, LVs cultivated in the field environment are susceptible to contamination from soil, irrigation water, airborne pathogens and animals, amongst other sources. They have a large surface area to volume ratios allowing for more pathogen attachment site (Gil et al., 2015). Once pathogens contaminate the plant, they can survive on its surface, including through the formation of biofilms and multiply rapidly in injured tissues. Laboratory studies suggest that pathogens can also become internalized within the plant tissue via stomatal pores (Li et al., 2024; Lim et al., 2014).

To address the microbial risks associated with LVs, the industry currently relies on preventative controls proposed by voluntary Global Food Safety Initiative (GFSI) Recognised Food Safety Management

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Schemes (e.g. Global G.A.P.; FSSC 22000; SQF Food Safety and Quality Codes) as set out by the Code of Hygienic Practice for Fresh Fruit and Vegetables (Food and Agriculture Organisation, 2003). This helps growers and processors with on-farm and post-harvest food safety, quality and environmental certification (Allende & Monaghan, 2015; Frankish et al., 2021). In terms of food safety, clearly the first risk reduction step in the supply chain from farm to consumer is to prevent microbial contamination of the crop by managing sources of contamination on the farm such as contaminated water and animal manures. These pre-harvest best practices aim to ensure that the product, farm and harvesting machinery are at reduced risk of pathogen contamination and cross-contamination. However, they do not address the risks from pathogen contamination that may already have occurred.

Following harvesting, the industry utilises post-harvest washing of the produce, for removal of gross soil, debris and dust. Sanitizers are often added to the wash water to reduce microbial load and the potential for cross contamination from the wash water (Gombas et al., 2017; Du et al., 2024). Nevertheless, not all LV crops will be washed post-harvest, and post-harvest washing will not completely eliminate or prevent cross contamination that occurred during the pre-harvest period. Post-harvest wash water has also been identified as a risk factor for pathogen cross-contamination from samples of LV that are contaminated to the bulk crop that was previously free of contamination (Murray et al., 2017; Rosberg et al., 2021). *E. coli* and *Salmonella* Typhimurium can be reduced but not removed completely from lettuce leaf surfaces once attached after inoculation (i.e., during pre-harvest), even after several post-harvest wash treatments with a chlorine-based sanitizer (Banach et al., 2017). Some foodborne pathogens can also enter a temporary 'viable but not culturable state' after being exposed to a sanitizer (Ferro et al., 2018; Highmore et al., 2018) though whether this is relevant to field conditions remains to be determined (López-Gálvez et al., 2017). The fact that outbreaks associated with consumption of LVs continues to occur arguably suggests that reliance on post-harvest sanitization alone to manage food safety risks in the modern LV industry may not be adequate (Banach & van der Fels-Klerx, 2020; FDA, 2017; Frankish et al., 2021).

The LV industry could potentially further reduce risk by implementing additional safety interventions such as including the pre-harvest application of a chemical sanitizer to the crop. In concept, effective sanitizers could be applied to crops via irrigation water or via boom sprayers. This is in addition to any chemical disinfection of the irrigation water and system, which is already commonly practiced, killing any pathogens in the irrigation water as well as preventing bio-film fouling of irrigation pipes, and consequential blocking of low-pressure drippers (Dandie et al., 2020).

Industry experts, particularly in Australia, noted that applying water treated with sanitizers directly to the crop at preharvest stage, is currently not widely used by the LV industry (Hort Innovation, 2024). There remain many questions on whether a pre-harvest crop sanitization strategy would be feasible, cost-effective, or even environmentally advisable for widespread commercial use.

Recent peer-reviewed reviews have focused on the feasibility of various disinfection technologies to disinfect irrigation water only (Dandie et al., 2020; van Asselt et al., 2021; Gurtler & Gibson, 2022). Public sources suggest that ozone systems (for example <https://ingenieriadeloazono.es/en/agricultural-ozone/>) are already commercially available for agricultural irrigation high flow capacity (50–150 m³/ha) to both 'reduce biofilm of the pipes' and potentially to 'sanitize your crop'. However, published scientific evidence to support these claims, or determine potential ecological impacts, is lacking.

This review was, therefore, undertaken to provide: (i) an overview of current farm management practices to reduce contamination prior to harvest, (ii) an evaluation of the potential for chemical sanitization of the crops in the field via treated irrigation water or sanitization sprays, (iii) a summary of our current knowledge of the efficacy of chemical sanitizers in disinfecting irrigation water, and (iv) identify the

knowledge gaps and barriers, as well as explore the future prospects to industrially applying pre-harvest sanitization technologies. Given the scarcity of evidence-based research on the viability, benefits and risks of pre-harvest sanitization strategies on managing microbial load, the review considers both peer-reviewed and publicly accessible information.

2. Farm management to reduce food safety risks in the field

Foodborne pathogens are reported to survive and persist in the environment for years (Jacobsen & Bech, 2012). *L. monocytogenes*, as a pathogen of high concern for LV's contamination, is able to grow in a wide variety of ecological habitats from soil and decaying vegetable matter, to also infecting animals, birds and people (Sauders & Wiedmann, 2007). This widespread occurrence and persistence of pathogens allows contamination to occur through multiple pathways, such as contact with contaminated dust, soil, soil amendments, irrigation water, animal incursions, and human contact during harvesting, harvesting/processing equipment, and wash water (Mogren et al., 2018).

Farm management and agronomic practices are key factors that contribute to reducing the microbial hazards associated with LVs. They have already been extensively reviewed (Devarajan et al., 2023; Gil et al., 2015; Gutierrez-Rodriguez & Adhikari, 2018). Among these practices, irrigation water, soil management and proximity to animal production are considered the most effective targets (Devarajan et al., 2023) with approaches including animal exclusion, water treatment, manure treatments or bans, and soil solarisation (Mogren et al., 2018). Other practices that reduce the risk of microbial contamination of LVs include regular cleaning (e.g., premises, facilities, harvesting equipment, tools, machinery) along with food safety instructions and training for staff (Frankish et al., 2021), wild and domestic animal management (e.g., fencing, buffer areas, exclusion periods) (Patterson et al., 2018), and general agronomic practices that improve the overall resilience of the agrosystem (e.g., short term cropping, vegetated filter strips, pesticide application) (Gutierrez-Rodriguez & Adhikari, 2018; Lenzi et al., 2021).

A reduction in the microbial risks associated with LVs could potentially be achieved through the selection of varieties or cultivars with different susceptibilities to pathogen attachment and persistence of the pathogen (Melotto et al., 2020). Plant susceptibility is due to the involvement of leaf morphology (e.g., wax, veins, stomata, trichomes, roughness and wettability) in pathogen attachment and further persistence, which varies among different leafy crop species, types of the same species and even cultivars (Frankish et al., 2021). Indeed, it has frequently been reported that pathogen attachment and persistence positively correlate with stomatal density, stomata size and surface roughness (Jacob & Melotto, 2019; Palma-Salgado et al., 2020). From a practical perspective, if conditions are less than optimal, producers may potentially choose to grow more robust varieties/cultivars (e.g., lamb's lettuce and wild lettuce) rather than those that may have higher risks of microbial contamination (e.g., rocket and Swiss chard) (Truschi et al., 2023) though this may be dictated by market requirements.

Good agricultural practices reduce risks of contamination, but most do not actively treat existing contamination if it occurs. Many farm management practises also remain understudied, making it difficult to accurately evaluate their efficacy in minimising microbial risks (Devarajan et al., 2023). Controlling food safety risks through farm management alone cannot be solely relied upon given the complexity of different production systems combined with many additional interacting variables, including season, weather conditions, and growing regions (see Fig. 1) (Devarajan et al., 2023). It has been concluded that a multi-faceted approach of preventing and treating pathogen contamination is required to effectively manage pre-harvest safety of LVs (Devarajan et al., 2023; Mogren et al., 2018).

2.1. Water management

Contamination of LVs via irrigation water is considered a major

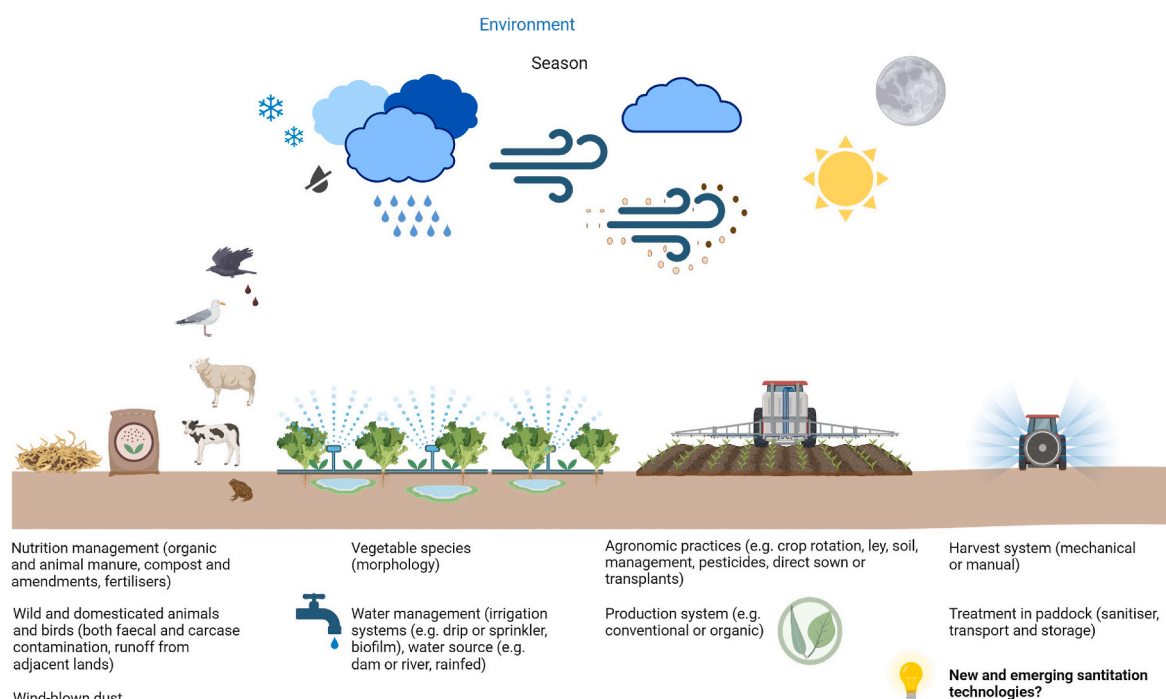


Fig. 1. Pre-harvest factors influencing contamination risk of foodborne pathogens in field production of leafy green vegetables that need to be considered separately and for interactions. Created with [BioRender.com](https://www.biorender.com). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

potential risk factor and has been directly linked to multiple outbreaks associated with LVs. A review by [Devarajan et al. \(2023\)](#) identified eight studies that directly showed sources of irrigation water affecting food safety risks. Surface water (i.e., irrigation channels, rivers, creeks, lakes, and on-farm reservoirs) posed greater risks compared to municipal, and ground water. Surface water is inherently susceptible to faecal contamination, run-off and seepage. The prevalence of pathogenic bacteria in irrigation water depends on a number of factors that include distribution system, season, geographical location, exposure to animal activity and animal manure-based fertilisers, and weather conditions ([Gil et al., 2015](#)).

Regardless of the source of water, testing the quality of the irrigation water is mostly self-regulated and relies on industry-lead certification guidance rather than legislated rules to achieve food safety ([White, 2022](#)). For example, in Australia, growers are required to test the microbial quality of their water supplies monthly during the period of use, or annually following four consecutive tests below specified microbial limits (i.e., < 100 *E. coli* cells per 100 mL if applied within 48 h of harvest to the edible portion of a crop usually eaten raw and/or minimally processed) ([Freshcare, 2020](#)). In comparison, in USA, there is no irrigation water testing requirement for *E. coli* ([FDA, 2023](#)). Instead, the Food Safety Modernisation Act Produce Safety Rules was recently revised in May 2024 to allow for systems-based water assessments for hazard identification and risk management decisions-making purposes ([FDA, 2023](#)).

The withholding period between irrigation and harvesting (see Section 2.2 for more details) are recommended to be of sufficient length for possible pathogens on the LV crop to 'die-off' (inactivation of the pathogen) via exposure to potentially harsh, dry conditions in the field ([Gutierrez-Rodriguez & Adhikari, 2018](#)). However, the rate of pathogen die-off depends on crop types, potential leaf damage, and environmental conditions, especially the dynamic changes in temperature, relative humidity, sunlight UV intensity, soil type and the existing soil microbial community ([Gutierrez-Rodriguez & Adhikari, 2018](#)).

The method of irrigation is an important farm management practice that needs to be considered in reducing microbial load in LV production

([Fonseca et al., 2011](#); [Gil, 2021](#)). The review by [Devarajan et al. \(2023\)](#) concluded that the use of sprinkler, spray, and foliar irrigation typically generated higher food-safety risks compared to furrow and drip irrigation systems. This is most likely due to direct contact of the water with the fresh product when the former irrigation systems are applied. For example, *E. coli* levels on lettuce were found to be higher (4–6 versus <1 log CFU/g) when irrigated with inoculated water via sprinkler systems compared to furrow and drip irrigation systems ([Fonseca et al., 2011](#)). This is because splash events (e.g., from sprinklers or rain) can transfer pathogens present in the irrigation water and soil to the surface of the fresh produce ([Lee et al., 2019](#); [Weller et al., 2017](#)). Irrigation methods that avoid or minimise contact between the irrigation water and the edible portion of a crop are, therefore, considered preferable for reducing contamination risk ([Allende & Monaghan, 2015](#); [Gil, 2021](#)) but may not be practical for all crops due to differences in cropping systems and soil types.

2.2. Soil management

Ground moisture and exposure to soil constitutes a food safety risk for LVs ([Devarajan et al., 2023](#); [Gutierrez-Rodriguez & Adhikari, 2018](#)). As reviewed by [Doren et al. \(2022\)](#), the role of mulch in the survival and spread of food borne pathogens has shown to be variable – it may promote pathogen persistence in the soil or it may also hinder direct contamination from soil by acting as a barrier. Soil and mulch can become contaminated through amendments such as manures and bio-solids as fertilisers ([Phan-Thien et al., 2020](#)), as well as via contaminated water, previous land use including animal presence, and other anthropogenic activities ([Gutierrez-Rodriguez & Adhikari, 2018](#)). Composting of soil amendments has been associated with improved food safety outcomes compared to using raw manures ([Devarajan et al., 2023](#)). Further, pathogen die-off in the field could be enhanced by maximising the time interval between application of soil amendments and time of harvest ([Devarajan et al., 2023](#); [Gil et al., 2015](#)).

Guidelines on the length of withholding periods to allow for pathogen die-off vary between standards and countries. For example, a

minimum of 60 days is required for [GlobalG.A.P.](#) Integrated Farm Assurance Smart (2024), 120 days for high-risk products is advised by the U.S. Department of Agriculture ([USDA, 2024](#)) and Canada ([CanadaG.A.P 2021](#)) and 45–280 days (depending of air temperature) for the Harmonised Australian Retailer Produce Scheme ([HARPS, 2022](#)) and 365 days for Californian Leafy Greens Marketing Agreement ([Products Handler Marketing Agreement, LGMA, 2023](#)). It is important to note that these exclusion periods do not necessarily align with the scientific evidence on the survival and persistence of bacterial pathogen in the field, which has shown to be up to one year or longer ([You et al., 2006](#)). For instance, *E. coli* O157:H7 and *S. Typhimurium* were found to persist for more than 100 days in soils amended with untreated manure ([Ramos et al., 2021](#)) while *E. coli* O157:H7 was shown to survive over 226 days in manure-amended soil stored at 15 °C ([Jiang et al., 2002](#)).

3. Potential antimicrobials for pre-harvest application on LV crop

3.1. Chemical sanitizers for application on crops

Conventional horticultural practice typically involves the implementation of a chemical program to manage plant bacterial and fungal pathogens that can damage crop yields and reduce shelf life. For example, in Australia, all chemical usage is regulated by the Australian Pesticides and Veterinary Medicines Authority (APVMA) under a permit approval system (<https://www.apvma.gov.au/>). This includes the use of sanitizers for water, soil or equipment used in the field. There are also

many chlorine-based products that are listed by APVMA as approved for post-harvest washing. However, it is worthy to note that there are currently no sanitizers that have been approved specifically as a microbiocide for pre-harvest application on food crops by the APVMA. The process to obtain approval by APVMA can be challenging and costly, and it highly likely that this situation is not unique to Australia. In the European Union, sanitizers used in agriculture to reduce microbial contamination before harvest are considered biocides, as regulated by the European Chemicals Agency (ECHA). Any biocidal product intended for pre-harvest use must go through a rigorous approval process, which includes an evaluation of the active substances to ensure they meet safety standards for human health, the environment, and food safety (as outlined in Regulation (EU) No 528/2012; [Eur-Lex, 2024](#)).

Emerging technologies, potentially suitable for in-field pre-harvest sanitization of crops via irrigation water, have garnered increasing attention. These are either as oxidising chemical concentrates (e.g., hypochlorite, peroxyacetic acid, hydrogen peroxide, 1-chloro-3-bromo-5,5-dimethylhydantoin, chlorine dioxide) or from on-site manufacturing units such as for producing electrolyzed oxidising water (EOW) ([Ogunniyi et al., 2021](#); [Shang, et al., 2023a, 2023b](#)). These technologies draw from current fertigation and spraying systems for plant pathogen management. However, to our knowledge, very few studies have examined the efficacy of pre-harvest sanitization of LVs by directly assessing the microbial reduction on the crop itself, and most of them were conducted over the past three years ([Table 1](#)).

These studies have shown promising results confirming the efficacy of the various sanitizers to reduce microbial load and foodborne

Table 1
Selected examples on the efficacy of pre-harvest sanitizer application to reduce foodborne pathogens on crops.

Study	Application method	Inoculated bacterial load on crop	Sanitizer	Crop	Log reduction on plants ^{a,b}	Sensory effects
López-Gálvez	Field trial (no inoculum)	<i>E. coli</i> field population of the water <i>Enterobacteriaceae</i> of the plant	Hypochlorite (<1 mg/L)	Baby spinach	<i>E. coli</i> counts (0.2–0.3 log reductions) of the water only <i>Enterobacteriaceae</i> : NS	Reduction in photosynthesis Build-up of chlorate (up to 0.99 mg/kg)
Ogunniyi et al. (2021)	Glasshouse trial (25 L of solution over 10 min; equivalent to a 6 mm irrigation event; harvested 1–2 h later)	<i>E. coli</i> , <i>S. Enteritidis</i> and <i>L. innocua</i> (~1 × 10 ⁹ CFU per plant) Air-dried for 2–3 h before application of sanitizers	Neutral electrolysed oxidising water (50 ppm free chlorine)	Cos lettuce Baby spinach	<i>E. coli</i> : 0.7 <i>S. Enteritidis</i> : NS <i>L. innocua</i> : 0.8 <i>E. coli</i> : NS <i>S. nEnteritidis</i> : 1.4 <i>L. innocua</i> : 1.4	No visual differences pre- or post-harvest
Shang, Zheng Tan, et al. (2023)	Field trial (inoculum sprayed evenly with shoulder spray). Harvested 24 h later	<i>L. innocua</i> (~1 × 10 ⁸ CFU/mL) Air-dried for 30 min before application of sanitizers	Sodium hypochlorite (50 ppm free chlorine)	Cos lettuce	Only reduced <i>L. innocua</i> by 0.8	Negative effects on leaf appearance for both varieties Sensory quality and shelf life similar to control
			Neutral electrolyzed oxidising water (20 ppm)	Baby spinach Mizuna, rocket, red chard, spinach	No effect on all species 0.8–2.5	
			Peroxyacetic acid (80 ppm)	Mizuna, rocket, red chard, spinach	2.4–5.5	
Shang, Huang, et al. (2023)	Glasshouse trial (harvested 120 min later.	<i>E. coli</i> and <i>L. innocua</i> (~1 × 10 ⁸ CFU/mL) Air-dried for 30 min before application of sanitizers	1-bromo-3-chloro-5,5-dimethylhydantoin (20 ppm)	Mizuna, rocket, red chard, spinach	0.2–1.5	NA
			Neutral electrolyzed oxidising water (5 and 20 ppm)	Mizuna, rocket, red chard	<i>E. coli</i> : 1.7–2.7 <i>L. innocua</i> : 1.5–2.8	
			Peroxyacetic acid (80 and 150 ppm)	Mizuna, rocket, red chard	<i>E. coli</i> : 1.6–3.8 <i>L. innocua</i> : 2.1–2.7	
			1-bromo-3-chloro-5,5-dimethylhydantoin (5 and 20 ppm)	Mizuna, rocket, red chard	<i>E. coli</i> : 1.1–2.2* <i>L. innocua</i> : 1.1 - and 2.3	

^a Compared to water controls.

^b Where multiple concentrations were tested, results reported with lower concentration first followed by higher concentration.

NS = not significant.

NA = not assessed.

pathogens on LV crops in the field (López-Gálvez et al., 2018; Shang, Zheng Tan, et al., 2023) and glasshouses/hydroponic systems (Ogunniyi et al., 2021; Shang, Huang, et al., 2023). Across all three studies, neutral EOW (hypochlorous acid, 20–50 ppm) was found to be effective against *E. coli* and *Listeria innocua*, resulting in a reduction of at least 0.7 to 3.8 log CFU/g depending on the crop type (Ogunniyi et al., 2021; Shang, et al., 2023a, 2023b). Peroxyacetic acid or PAA (80–150 ppm) was typically more effective, where reductions in *E. coli* and *L. innocua* ranged between 2.5 and 5.5 log CFU/g (Shang, et al., 2023a, 2023b). Furthermore, out of the tested sanitizers, there appeared to be little negative impact on the sensory qualities of the produce pre- or post-harvest, with the exception of sodium hypochlorite (50 ppm) where severe necrotic zones and yellowing/browning of leaves occurred prematurely (Table 1). In addition, application of 1 mg/L of hypochlorite in the irrigation water was found to reduce photosynthetic efficiency of baby spinach and also resulted in the build-up of chlorate residue (López-Gálvez et al., 2018). We found only one other study that examined pre-harvest sanitation in another horticultural crop (Zhao et al., 2021). found pre-harvest sanitation with the bactericide comprised of levulinic acid (0.5%) and sodium dodecyl sulphate (0.5% SDS) reduced foodborne pathogens (*E. coli* O157:H7, *Salmonella*, and *L. monocytogenes*) and microbial loads of pot-grown tomato grown under full sun by an average of 1.7 log CFU/fruit. These studies applied sprays pre-harvest up to 2 h prior to assessment but these short timeframes may not accurately reflect field conditions, given that longer times would be required by a grower to apply sanitizer treatments over extensive crop areas (Shang, Zheng Tan, et al., 2023).

It is important to note that the high inoculum levels (>5 log CFU/g) of specific pathogens used in these studies are not likely to frequently occur in the field. For example, Holvoet et al. (2014) found that in most cases the natural *E. coli* contamination levels on lettuce were below <0.7 log CFU/g across four open field farms, with one farm having slightly higher levels of between 2 and 3 log CFU/g in less than 10% of samples (Holvoet et al., 2014). Therefore, from a practical perspective, a 1–2 log reduction is likely to be sufficient to provide appropriate levels of food safety under most natural contamination levels. However, in-field trials, are warranted and would need to consider a number of factors including sanitizer type, concentration of sanitizer, volume/coverage of spray and sanitizer contact time (Shang, Zheng Tan, et al., 2023).

3.2. Other antimicrobials for application on crops

Apart from chemical sanitizers, other antimicrobials have recently emerged as potential options for pre-harvest application to reduce foodborne pathogens in LV crops. These include bacteriophage and lactic acid bacteria (LAB) treatments, which are considered safe, effective, and natural antimicrobials for fresh produce. Furthermore, these approaches are thought to have low impact on sensory qualities of the produce (Lenzi et al., 2021). However, most of the research has been done in a post-harvest context and adoption as a spray treatment in a pre-harvest context would arguably be expensive and unfeasible due to the scale required. There are currently limited studies that have investigated the application of phage-based sanitization for pre-harvest control of pathogens on LVs, however, its efficacy is restricted by the high specificity of the phage to the host (Bumunang et al., 2023), and only one for the application of LAB (Yin et al., 2023). Specifically, Yin et al. (2023) highlighted the potential efficacy for LAB treatments as it was evident that after electrostatically spraying lettuce crops with a cocktail of LAB (8 log CFU/ml containing *Lactococcus* spp. and *Lactiplantibacillus* sp.), *L. monocytogenes* and *E. coli* O157:H7 numbers were reduced by ~2 and 1 log units, respectively. Despite these promising results, the practicability and ecological impacts of innovative biological treatments such as LAB and bacteriophage for pre-harvest control of pathogens on LVs must also be considered in relation to associated costs, e.g. of 'scaling up' and ability to withstand environmental fluctuations (Imran et al., 2023).

4. Reducing microbial load from irrigation water

Disinfection technologies could allow growers to broaden their options for irrigation water sources without relying on frequent microbial testing to account for potential changes in water quality (Allende & Monaghan, 2015). Currently there are a range of physical and chemical technologies that have been demonstrated either alone, or in combination, to be effective for disinfection of irrigation water (Meireles et al., 2016; van Asselt et al., 2021; Irakoze et al., 2022; Supplementary Table 1).

While physical/mechanical technologies such as membrane filtration, slow sand filtration, ozone and UV irradiation (Banach et al., 2021) are considered beyond the scope of this review, it is worthy to mention that the main advantage for physical/mechanical treatments is that they do not form potentially hazardous disinfectant by-products and regulatory guidelines around their use are less onerous (Dandie et al., 2020; van Asselt et al., 2021). However, the main disadvantage of physical/mechanical technologies is that there is no residual effect beyond the specific treatment time. Further, many of the physical treatments also reduce turbidity, suspended solids, and organic matter, therefore enhancing the effectiveness of any subsequent physical (e.g., ultraviolet or ionising irradiation) and chemical sanitising treatments (Banach & van der Fels-Klerx, 2020; Dandie et al., 2020).

By comparison to physical/mechanical technologies, implementation of chemical sanitization technology is relatively straight forward, requires low energy input and generally involves low maintenance. Based on knowledge gained in post-harvest processing activities comparatively safe sanitizers tend to be weak acids that are strongly electrophilic and possess a degree of oxidation selectivity, including ClO^- , ClO_2 , HOCl, HOBr, ozone (O_3), peroxides (H_2O_2 , PAA), and natural organic acids (e.g., lactic acid, citric acid) (Feliziani et al., 2016). The reviews by Raffo and Paoletti (2022) and Dandie et al. (2020) have already provided detailed information on the advantages and disadvantages of common chemical sanitizers. However, it should be noted that with these chemicals, safety is a relative term. For example, HBrO (hydrobromous acid) is one of the most powerful known electrophiles but it is this reactivity that makes it environmentally hazardous (Raffo & Paoletti, 2022). As a result, chemical sanitizers that are useful are constrained by many factors including efficacy, cost, safety during use, and ecotoxicity. Further, some chemical sanitizers, such as chlorine and bromo-chloro dimethyl hydantoin, can pose healthy safety concerns due to the potential formation of toxic disinfectant by-products (DBPs) (Raffo & Paoletti, 2022). The exact chemicals used, however require individual appraisal of risk from exposure, during application and the presence of residues (Santos et al., 2023).

Studies to date have primarily focused on evaluating the efficacy of chemical sanitizers to treat wash water in LV post-harvest systems rather than pre-harvest irrigation systems (Supplementary Table 2). This is because these same sanitizers have traditionally not been used to disinfect irrigation water although many have use in disinfection of cooling water towers, swimming pools and spas. However, it may be possible to draw from the knowledge gained from the many post-harvest sanitization studies that examined the key factors influencing their efficacy. Overall, chemical sanitizers are sensitive to the water quality parameters such as turbidity, pH and organic load. Therefore, treatment concentrations need to be optimised and monitored regularly with sensors to ensure accurate dosages, and in some cases, water may require pre-treatments such as filtration or pre-oxidation to reduce organic load (Santos et al., 2022).

Comparison of the efficacy of sanitizers is difficult given the wide range of test variables across studies, along with there being fewer relevant experiments comparing different sanitizers in parallel. Of particular note, Ogunniyi et al. (2019) compared the efficacy of pH-neutral EOW, sodium hypochlorite, and chlorine dioxide against *E. coli*, *L. innocua* and *Salmonella* in simulated irrigation water with increasing organic matter content. The efficacy of EOW containing 5

ppm free chlorine equivalents was unaffected by increasing organic matter (i.e. dissolved organic content of 40 mg/L) and compared favourably with equivalent concentrations of sodium hypochlorite, and chlorine dioxide (Table 1). EOW was more effective, compared to the other sanitizers, in the presence of high dissolved organic carbon (20–100 mg/L) when applied at a higher concentration of 20 ppm free chlorine equivalents.

Murphy et al. (2023) reported the efficacy of chlorine (calcium hypochlorite; 2–4 and 10–12 ppm) and PAA (6 and 10 ppm) against *Salmonella* in pond and river irrigation water with up to 10 min contact time (Supplementary Table 1). Irrespective of all other factors like contact time, temperature, and water quality, the results demonstrated that the reductions of *Salmonella* by chlorine were 3.25 log greater than that of PAA. Different results between studies may be attributed to the target organisms tested (e.g. *Salmonella* vs mesophilic aerobic bacteria), contact time (30 min vs 24 h) and nature of the organic loads in the water samples tested. This suggests that the different scenarios where sanitizers are being applied pre-harvest require investigation. Currently we lack empirical knowledge to accurately predict the efficacy of sanitizers and thus still require ground truthing to arrive at optimal recommendations.

5. Research needs and future perspectives on applying pre-harvest sanitization technologies

Despite considerable research on post-harvest sanitization of LVs, there are relatively few refereed publications on evaluating pre-harvest sanitization approaches. We can assume that chemical sanitation technology that can disinfect irrigation water has provided a base of evidence of net-positive impacts that pre-harvest sanitization could generate. The main challenge is to determine what pathways can best enable industrial pre-harvest sanitization. A review by Van Haute et al. (2015) broke down this to pathways of costs, safety, and environmental impact.

5.1. Developing a risk framework where the need for pre-harvest sanitization could be justified

Pre-harvest safety interventions could be considered under a validated risk framework where risks of pathogen contamination are estimated. This would include the risk of contamination via transfer of water as well as, animal contaminated soil and dust particle deposition onto plants, processes that can be exacerbated by climate events (Miron et al., 2023), such as major rainfall and moderate to high velocity wind events. These processes represent potentially measurable risks, however yet remain to be conceived in a quantitative microbiological risk assessment-like framework. Other possible measurable hazards that may be relevant involve, for example, the movements and distributions of wild animals or adjacent domesticated animals (Jeamsripong et al., 2019). Other sources of microbial contamination are possible, such as the sources of water used for irrigation. The development of a probabilistic risk framework that considers a suite of scenarios that could increase contamination potential in farming systems (Buscaroli et al., 2021) may then better frame the usefulness of pre-harvest interventions described earlier in this review. Until this happens net benefits can only be assumed. Having actual evidence of utility could then allow greater opportunities to quantitatively predict effectiveness of different pre-harvest antimicrobial interventions within the LV supply chain. This is useful since the production phase should not be seen in isolation, but rather considered with other requirements for LV products, such as spoilage mitigation and smart packaging options (Karanth et al., 2023) particularly given that the commercial feasibility of LVs and their inherent health-related value is tied to both safety and quality.

5.2. Challenges of cost-effectively managing large scale disinfection of irrigation water

The availability and cost of irrigation water is often very competitive, and potentially the water is of highly variable quality (Bhagwat, 2019). In dry periods, there is often a need for water storage in ponds and man-made reservoirs thus increasing the risk and level of biological contamination (Jiang et al., 2019). The use of chemical sanitizers or physical technologies (see Section 3) that allow water to be effectively treated to potable standard have long been established for domestic and industrial processing water supplies. Smaller scale decentralised treatment of water, in a world where water scarcity has become a serious issue, is likely to become a normal requirement (Siwila & Brink, 2018). However, the cost efficiency of using existing or newer, more sustainable technologies to treat pre-harvest irrigation water, whether through on-site treatment (Mishra et al., 2023) and/or supplied via boom sprayers on a tractor, is yet unclear for large scale agricultural or horticultural activities under the diverse possible scenarios and variable water quality inputs.

Non-protected, LV agriculture requires water quality systems appropriately engineered to allow producers to be able to access water that could be variable in initial quality. This entails potentially significant capital costs and has already been considered extensively in protected horticultural systems that are moving towards technological sophistication. Even then the actual production efficiency, economic and safety advantages though highly touted have still to be conclusively quantified either economically (Moghimani & Asiabanpour, 2023) or in terms of biological risk control (Hamilton et al., 2023). Overall, available technology would need to be assessed to determine the most effective and affordable options to be integrated into agricultural water deployment systems.

5.3. The efficacy and cost-benefit of applying pre-harvest sanitizers to crops

For implementing pre-harvest interventions, producer costs can include the costs of the chemicals, any additional capital infrastructure needed to implement chemical applications, as well as the labour, training and quality monitoring needed to run the system in a safe manner. However, given the current lack of scientific information on the efficacy of this technology, it may be seen by producers as adding an unnecessary cost and that risks, for example from weather, is simply part of doing business and there are limits on how proactive farmers can practically be (Ricart et al., 2023).

Implementation could also consider a risk assessment to determine if irrigation water disinfection is warranted in the first place and then if required, other factors would need to be considered including the effects of timings, frequency and application rates of treating irrigation water and/or using irrigation water to treat crops pre-harvest. Sanitizers could, ideally, be applied just once prior to harvest as a final 'rinse' either in the irrigation water or delivered as a spray in a similar way to pesticides. This is basically a one-step pre-harvest treatment that could be used selectively to augment post-harvest sanitization processing. Based on recommended commercial dosage rates applied post-harvest, the estimated costs of four commonly used post-harvest sanitizers for a final rinse were calculated and summarised in Table 2. However, the efficacy of sanitizers as listed in Table 1 suggest that meaningful log reductions could be achieved even at much lower concentrations than the values presented in Table 2. Therefore, the approximate cost of the sanitizer may be even less than calculated in Table 2, notwithstanding the initial capital costs for storage, production and application equipment. Cost-benefit analysis should also consider indirect costs such as the additional time that may be required to clean equipment to minimise unknown interactions between sanitises and any agronomic chemicals that are being mixed in spray booms.

Table 2

Estimated cost of four common sanitizers in Australia if applied in irrigation water for a final crop 'rinse'. This does not factor the cost of water as water is already used for irrigation. All costs are in US dollars.

Sanitizers	Recommended level (ppm) ^a	Cost per hectare ^b	Capital costs ^c
Chlorine	25–80	\$275–\$881	Up to \$23K
Peroxyacetic acid	20–80	\$295–\$1182	Up to \$23K
Electrolysed oxidising water	2–20 (as free chlorine)	\$5–\$50	Up to \$24K for a generator and installation for automated dosing systems
1-bromo-3-chloro-5,5-dimethylhydantoin	5–10 (as free chlorine)	\$128–\$256	\$561–\$792 for an erosion feeder to disperse concentrate plus automated dosing systems

^a Higher end of the recommended level is based on post-harvest conditions.

^b Cost was estimated based on dilution of concentrates and assumed that 300,000 L is used per hectare (i.e., coverage is assumed to be a 3 mm depth purely from a single spray); Cost of each sanitizer was obtained directly from distributors located in Australia.

^c Costs required for equipment and installation for automated dosing systems.

5.4. Effect of pre-harvest sanitizer residuals on ecosystem health

The effects of pre-harvest sanitizer residuals on long-term ecosystem health from multiple applications is currently largely unknown. This includes the effect on soil health, natural leaf and soil microbiome (e.g., rhizosphere) that may in fact act as protection against contamination with plant and human pathogens (Dandie et al., 2020) and on plant physiology and quality (see below). Further, the impact of pre-harvest sanitizers on the accumulation of DBPs in the environment and in the harvested product remains unknown and warrants investigation. The potential effects will depend on many variables, such as the type of sanitizer and its concentration, and the frequency of application. For instance, a recent glasshouse study by Lombi (2021) found that the application of EOW (5 ppm) spray resulted in minimal change in soil properties (pH, electrical conductivity) for all soils tested when applied once a week over a 14 week period. In contrast, under the same conditions, application of sodium hypochlorite significantly increased soil pH for the majority of soils tested. Further, there remains uncertainty on whether or not multiple applications of NaCl enhanced production of EOW would contribute to higher soil salinity, although this is unlikely given that the concentration of NaCl is EOW is 0.26% wt/vol (Envirolyte, 2024). More expensive KCl-based EOW could be used to overcome this problem with dual nutrient potential (Ogunniyi et al., 2019). More research is required to evaluate this further in the field under a range of conditions.

Research is also required to assess the effects on microbial ecosystems, including the natural microbial community of the LV phylloplanes (Dakwa et al., 2021) and potential co-benefits to suppress plant pathogen populations (Zheng et al., 2008). However, the possible co-benefits of using water with sufficient residual oxidising activity to treat both plant and human pathogens on LVs are not known. The compatibility of sanitizers for use in conjunction with approved treatments of LVs (e.g., fungicides and pesticides) needs to be also evaluated to inform long-term soil and ecosystem health. While it is known that oxidising sanitizers can affect the efficacy of some pesticides and potentially interact with them, this knowledge is fragmentary and needs to be further detailed with use guidance for producers (Mueller et al., 2003).

5.5. Impact of pre-harvest sanitizers on plant and product quality

The potential effect of pre-harvest sanitizers on plant and product

quality is a significant concern to producers and is not well studied. The levels at which potential negative impacts occur to plant growth and sensory qualities will depend on many variables such as the type of sanitizer and its concentration, and the frequency of application (López-Gálvez et al., 2017). For example, practice evidence exists that single exposures to oxidation sanitizers up to 50 ppm chlorine equivalents damages fresh produce (Nguyen et al., 2019). In contrast, pre-harvest application of PAA (up to 150 ppm), EOW, and 1-bromo-3-chloro-5,5-dimethylhydantoin BCDMH (both up to 20 ppm free chlorine) to LVs had no effect on product appearance, colour, texture or odour but also did not extend shelf-life at 4 °C (Shang, Huang, et al., 2023). This may be due to a rapid deactivation of oxidising ability in the 24-h contact time suppressing bacterial growth during the initial stage of storage (up to 3 days) but otherwise did not influence subsequent bacterial outgrowth. The only extensive information available on sanitizer concentration versus impacts on plant health has been research on the impacts of chlorinated water supply. The chlorine concentration threshold above which damage plant health occurs from repeated regular over-head water is > 1–2 mg/L for many vegetables and seedlings but listed as >18 mg/L for lettuce and >50 mg/L for sweet pepper (Zheng et al., 2008). Furthermore, data on plant health after pre-harvest sanitization of mature LVs prior to harvest is not available but would be species dependent and resistance to oxidative damage may change with age and environmental exposure.

Overall, the limited existing data does not allow robust conclusions to be drawn considering the wide range of crops and scenarios in which sanitizers could be applied. The impacts of sanitizer types, concentration and frequency of applications on the resilience and quality of LVs grown commercially needs to be assessed more thoroughly and measured against the benefits of microbial pathogen load reduction.

5.6. Regulatory limitations in applications for pre-harvest safety

The lack of scientific evidence for pre-harvest sanitization technologies creates a gap in regulatory guidance being available for its use. This is especially for managing potential contamination with foodborne pathogens but recognising that longer term pre-harvest use could impact both the growth of plant pathogens or the effectiveness of plant sprays against plant pathogens. This includes constraints on usage owing to potential issues with residual chemicals in the field and on the crop, as well as user safety in deploying chemicals on a wide scale. Organic farming systems are controlled for pre-harvest sanitizer with restrictions for some sanitizers and approval for others such as EOW being approved as equivalent to chlorine for organic usage (USDA, 2014).

In terms of usage often the regulations are quite specific in that a sanitizer product has a prescribed use. For example, PPA (5% peroxyacetic acid) (Ayoub et al., 2017) is used as an antifungal agent in grapevine but is not approved for other applications. There is a precedence for approval of sanitizers labelled as microcides that can be applied pre-harvest but there is currently no approved advice on field use against foodborne pathogens in Australia, for example (Murphy et al., 2023). In the USA, there are a number of EPA-registered products based on PAA that have been approved for use in foliar sprays in addition to irrigation water systems pre-harvest. However, the majority of these have been approved to "control the growth of non-public health microorganisms that can cause spoilage" or "to cure or prevent bacterial and fungal diseases on growing agricultural crops." In contrast, only a few of these have been approved to reduce and control foodborne bacterial pathogens in preharvest irrigation water (Produce Safety Alliance, 2024). Fortunately, there is an emerging impetus for regulatory amendments, particularly in the US, where the Food and Drug Administration have recently developed a testing protocol to generate data on the efficacy of antimicrobial products to reduce foodborne pathogens, with the aim to support approval of chemical sanitization of irrigation water (FDA, 2023).

6. Conclusion

The increasing number of foodborne outbreaks and recalls associated with LVs highlights the need for additional strategies to reduce the safety risks of crop contamination in the field. The review identified viable pre-harvest interventions for disinfection of irrigation water and/or sanitization of the crop via irrigation water or sprayers. Recent studies confirmed the efficacy of pre-harvest sanitization of the crop to reduce pathogen contamination. There is already approval for specific sanitizers to be used for irrigation water treatment. However, the cost efficiency of these technologies at large scale agricultural activities under different scenarios and variable water quality inputs is unknown. Pre-harvest sanitization could also be used a strategy to mitigate microbial food safety risks associated with extreme weather events (e.g. dust storms and heavy rainfall splash), immediately prior to harvest. The review also identified numerous knowledge gaps and areas for research and development to enable adoption of pre-harvest sanitization technologies. Specifically, further research is needed to evaluate the efficacy of these interventions under different scenarios and how they affect the quality of plant/product and their ecosystem health. A risk framework for specific crops and scenarios should also be developed to justify the need for implementing pre-harvest sanitization.

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Declaration of competing interest

The authors declare that they have no conflicts of interest.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.tifs.2025.104928>.

Data availability

No data was used for the research described in the article.

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DPI Primefact

Microbial food safety risks associated with producing and processing fresh produce in bushfire-affected regions

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Are your fresh produce production fields or processing facilities in or near a bushfire-affected region? Or do you source fresh produce from that region?

Re-assess microbial food safety risks associated with displaced wildlife due to bushfires and their potential intrusion in the production fields, water sources and processing facilities.

Bushfires have a devastating impact on wildlife, causing profound ecological and environmental consequences. The intense heat and rapid spread of bushfires often destroy natural habitats, leaving animals without shelter, food, and breeding grounds (Figure 1). The immediate consequence includes wild animals (e.g. kangaroos, feral pigs, deer, rodents and marsupials) escaping the fire-affected areas and potentially entering the fresh produce production fields for shelter, water and food.



Figure 1. Bushfires can force wildlife onto fields used to grow fresh produce, causing contamination.

The wild animals not only damage crops, affecting the quality and quantity of produce, but also introduce the risk of faecal contamination, potentially compromising the microbial safety of fresh produce. The wild animals' faeces might contain foodborne bacterial pathogens such as *Salmonella* and *Escherichia coli* (Kilonzo et al. 2013; Potter et al. 2011). These pathogens can survive for a long time and remain capable of contaminating produce. Research has shown that *Salmonella* can survive in animal faeces for up to one year (Topalcengiz et al. 2020), allowing adequate opportunities for the pathogens to be transmitted to the fresh produce. A source attribution modelling study has established the direct transmission of *Salmonella* with wildlife and companion animals' access to macadamia plantations (Munck et al. 2020). Pathogen survival and persistence in production fields depend upon many factors such as soil type, temperature, moisture, sunshine, animal type and pathogen.

Transmission of foodborne pathogens from wildlife to fresh produce

The transmission of foodborne pathogens from animal faeces to fresh produce poses a significant risk to public health and food safety. When animal faeces come into direct contact with fresh produce or the surrounding soil (Figure 2), pathogens such as *Salmonella*, *E. coli* and other harmful microorganisms can be introduced. Other factors, such as sprinkler irrigation or rain splash and wind, can transfer pathogens from faeces on soil to produce (Weller et al. 2017). The pathogens can adhere to the surface of fresh produce, leading to contamination that can persist throughout the supply chain and reach consumers. The risk is exacerbated during the harvesting process, where contaminated produce can be inadvertently collected and distributed.



Figure 2. Animal faeces (circled in red) and tracks (circled in blue) are signs of wildlife intrusion in the production fields.

Heat-stressed wild animals escaping the bushfire zone would be attracted to surface water sources such as farm ponds and dams. Animals defecating in or near water sources can lead to microbial contamination of the water. Using the contaminated water for irrigation and applying chemical sprays can transfer the pathogens onto the fresh produce. Furthermore, wild animals are more likely to be shedding bacterial pathogens in heat-stressed conditions than in normal conditions.

If fresh produce that is contaminated with animal faeces is processed in a packing facility, it can contaminate the postharvest wash water and cause cross-contamination. The harvest bins, postharvest equipment and premises can also be contaminated with these pathogens, resulting in them becoming established in processing facilities. Once these pathogens are established due to biofilm formation on surfaces, routine cleaning and sanitisation processes might not be effective in eradicating them.

Risk management options

To mitigate microbial food safety risks associated with wildlife and bushfires, rigorous prevention measures, including regular field assessments, prompt identification of faecal contamination, and the implementation of proper hygiene and sanitation practices, are essential to safeguarding

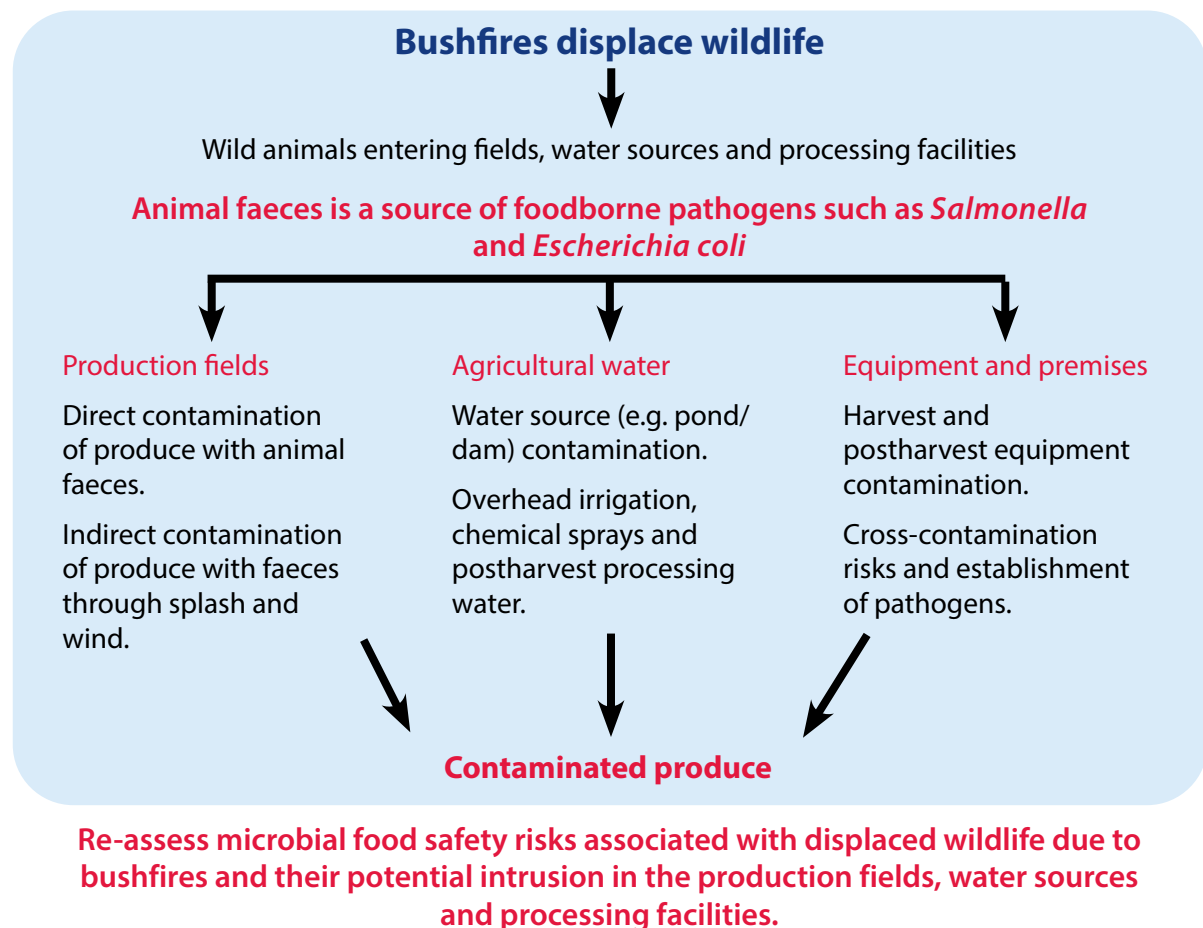
the integrity of fresh produce and ensuring the health and well-being of consumers. It is recommended that growers implement strategies to minimise the effect of wildlife on fresh produce microbial safety. The following measures are suggested:

- **Field monitoring:** growers should undertake inspections to look for signs of wildlife intrusion in standing crops and fallow land. Appropriate measures should be taken to minimise the microbial contamination risks.
- **Fencing and barriers:** physical barriers, such as fences and nets, can be installed to prevent wildlife from accessing cropped areas and water sources. This reduces the risk of faecal contamination of standing crops and water sources.
- **Preharvest inspection:** before each harvest, it is essential to conduct a thorough field assessment to verify the signs of animal intrusion or faecal contamination.
 - When faeces are discovered in the field or have directly contacted the produce, harvesting in that area (including buffer zones) should be avoided. Identify and mark the contaminated areas or produce and create a buffer zone. Buffer zones should have a radius of between 1 and 10 m, depending on the crop, production system, and animal type. The California Leafy Green Marketing Agreement recommends a minimum of 5 feet (~1.52 m) radius of buffer zone for leafy greens.
 - If faeces and contaminated produce can be easily removed and the contamination is relatively isolated, ensure thorough cleaning and sanitisation of all equipment involved in the removal process. Additionally, adhere to proper personal hygiene practices, such as handwashing, to minimise the risk of cross-contamination.
 - In cases of extensive faecal contamination or significant animal intrusion, refrain from harvesting the field. If there are any signs of a farm water source (e.g. pond or dam) being contaminated, a water sample should be submitted for microbiological testing. The water should only be used if it is not contaminated.
- **Educate harvest workers:** those involved in harvesting produce should be trained to look for signs of animal faeces in the fields, report it to the supervisor, and not harvest produce that could be directly or indirectly contaminated.
- **Inspect harvest bins:** ensure they are free from animal excreta, thoroughly clean the bins to remove any debris and foreign matter, and sanitise them.
- **Postharvest processing:** if harvested produce shows signs of animal faeces during processing, the operation should be stopped, and the harvested batch should be rejected. The processing equipment should be deep cleaned and sanitised. Concentrations of sanitisers in wash water and frequency of wash water change should be calibrated to compensate for the elevated risk of microbial contamination.
- **Packing or processing facilities:** thorough inspection, cleaning and sanitisation of processing facilities is recommended to minimise the risk of contamination and cross-contamination with microbial pathogens potentially linked to the wildlife in the field or processing premises. Rodent and vermin control measures should be revisited.

Summary

Growers should consider wildlife management in accordance with local regulations and without conflicting with environmental stewardship and conservation goals. A co-management approach that involves conserving soil, water, air, wildlife, and other natural resources while simultaneously minimising microbial hazards associated with fresh produce production is strongly recommended.

Bushfires can cause wildlife to affect fresh produce safety



Risk management

- Monitor wildlife in fresh produce production and processing environments.
- Fencing and barriers to prevent wildlife incursion.
- Preharvest inspection to determine the incursion and its scale.
 - Establish buffer zones around contaminated spots (isolated low level).
 - Remove the wildlife-affected crop and soil (isolated low level).
 - Refrain from harvesting (extensive damage).
- Educate workers to spot and report the intrusion signs (animal faeces and tracks) and to not harvest contaminated produce.
- Inspect harvest and postharvest processing equipment and premises.

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**Hort
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FUND**

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**Hort
Innovation** **VEGETABLE
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This project has been funded by Hort Innovation using the vegetable research and development levy and funds from the Australian Government. For more information on the fund and strategic levy investment visit horticulture.com.au

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The Safe Leafy Veg project provides insights into microbial risks and their management

24 February 2025

[Article](#) [Pests diseases and biosecurity](#) [Asian leafy vegetables](#) [Baby leaf](#) [Endive/radicchio/chicory](#)
[Leafy vegetables](#) [Lettuce](#) [Silverbeet](#) [Spinach](#) [Sprouts](#) [Other leafy vegetables](#)



Postharvest washing of baby leafy salad.

Project Code

VG22002

Short Summary

New lessons on ways to reduce the risk of microbial contamination in leafy vegetables are emerging from the Safe Leafy Veg project.

Year Published

2025

Project Provider

NSW Department of Primary Industries and Regional Development

By Dr Sukhvinder Pal (SP) Singh, Department of Primary Industries and Regional Development



of all scales.

The project's scope includes engaging with growers and processors to understand their food safety practices and preventive control measures. The response from growers has been overwhelmingly positive, indicating a strong willingness to adopt improved or new practices as needed.

Over 80 growers and processors have been visited across major leafy vegetable production regions, including East Gippsland, the Mornington Peninsula, Bacchus Marsh, Lower Murray, Adelaide-Virginia, Lockyer Valley, Fassifern Valley, Granite Belt, Perth Metropolitan, Gingin-Peel-Ord River, Greater Sydney, Riverina, and Tasmania. Growers and processors have shared critical control measures employed at production, harvest, and postharvest stages.

As part of the microbial risk mapping process, microbiological samples were collected from production (soil, water, produce, machinery), harvest (equipment), postharvest water, produce, premises and processing machinery) and retail stores (produce).

So far more than 8,000 microbiological assays have been conducted for three target pathogens (*Listeria monocytogenes*, *Salmonella* species and pathogenic *E. coli*) for their presence/absence. The aim of microbial risk mapping is to define the points of interventions to improve practices and direct resources of growers' levy funds to maximise the food safety improvement gains. All participating growers have been receiving food safety recommendations to implement in their businesses in short, medium, and long terms.

The key



Allowing irrigation water sediment to settle in farm ponds is important

learnings so far are highlighted below:

- Pathogenic *E. coli* is the leading microbiological risk identified in the risk mapping process and its potential sources and routes are speculated based on production practices. *Salmonella* and *Listeria monocytogenes* detections are relatively much lower. In 2025, whole-genome sequencing of these pathogens will provide deeper insights into pathogen reservoirs, transmission and persistence in the production and postharvest systems.
- Produce-pathogen pairing showed that herbs and lettuce showed higher association with pathogenic *E. coli*. Ready-to-eat baby spinach and mixed salads ranked lower to these products. Infrequent detections were observed in other leafy vegetables such as Asian vegetables, kale, chards, cabbages and spring onions.
- Among sources and/or routes of contamination, the following are of special interest:
 - Irrigation water quality (surface water)



Irrigation water microbial risks

Surface water sources (e.g. rivers, dams, creeks and farm ponds) are the most common sources of irrigation water for the field production of leafy vegetables and are highly prone to microbial contamination and seasonal variation compared to ground water sources.

Approximately 711 water samples have been collected from participating farms, that included monthly sampling from 12 water sources (rivers, creeks, and dams) directly feeding vegetable production system in different states.

- Surface water quality was observed to decline during summer (December–January) and improve during winter. While most sources met microbial quality criteria (<100 CFU *E. coli*/100 mL), some samples still showed the presence of pathogens like *Salmonella*.
- Though generic *E. coli* population proved to be a good indicator of water quality compared to coliforms count, there is still gap in risk assessment, especially when the water sources upstream have contamination risks.
- The data suggested that pumping water from rivers and creeks and allowing the sediment to settle in farm ponds before its application in irrigation improves water quality. Mixing of river water with ground water and then storing in farm ponds is a common practice to improve water quality.
- The presence of ducks and other water birds raises the risk of microbial contamination in farm ponds, depending upon the storage volume of water. Water birds' droppings collected from multiple farm ponds in several regions occasionally showed the presence of pathogenic *E. coli* but no *Salmonella* detections were observed.
- Some farm ponds receive run-off from vegetable and other crop production fields. This run-off could contain high levels of nutrients such as phosphorus leading to the development and proliferation of blue-green algae (BGA) in farm ponds. The risk of BGA toxins in these production farms is speculated to be higher as research studies have shown the translocation and accumulation of toxins from irrigation water in edible parts of crops.
- Overhead irrigation is common for baby leaf production while drip irrigation is popular for head leafy crops such as iceberg lettuce, cabbage and romaine. However, some farms have overhead irrigation system for head leafy crops as well. Depending upon the soil type, the overhead irrigation continues until the day of harvest.

Water quality and quantity are going to be major limitation factors in safe production of leafy vegetables. Preliminary recommendations on managing irrigation water risk, based on this project, are as follows:

- Identify and assess microbial risks associated with irrigation water sources, considering upstream contamination risks. Tabulate historical microbiological data on water quality and look at trends based on the seasons, water sources and major weather events during those periods.
- Water from rivers and creeks should not be directly pumped and used in irrigation systems. Sediment should be allowed to settle before its application.
- The water pumped from ponds should be passed through coarse filtration systems with frequent back flushing to further improve water quality. The project data from a farm using the filtration system showed that water quality measured as *E. coli* population was improved by this process. This practice during peak summers could further help mitigate risks associated with overhead irrigation water.
- With some practical and cost limitations, application of chemical sanitisers including chlorine and ozone are other options to enhance water quality.
- Heavy rainfall near harvest increases organic load on leafy vegetables via splashing, especially in heavier soils. Some growers use preharvest rinsing of standing crop with water containing a sanitiser to mitigate food safety risks associated with weather events.

Organic soil amendments risks



A soil boot swab by a farm staff member

Campylobacter. These pathogens survive in soils for extended durations (from days to more than a year) depending upon the pathogen type and population, soil type, soil temperature, soil moisture, cropping system and several other factors.

The safe use of raw untreated manures is a global debate as there is no scientific consensus on the fate of pathogen survival in real-world scenarios. As a result, leading food regulators (e.g. US FDA) have reserved their standing on the safe use of raw animal products in horticultural production systems. Global Food Safety Initiative (GFSI) certified schemes allow the use of raw manures with a range of exclusion periods for their

application. However, the use of composts containing animal products, conforming to Australian Standard AS4454, is considered safe.

The use of animal products (manures and composts) is a common practice in both organic and conventional production systems. However, baby leaf production systems were predominantly avoiding the use of animal products in soils and have adopted green manures (cover crops) to improve soil health. There are several compelling reasons for the use of animal products as a reliable source of soil and crop nutrition, circularity of plant-animal industries, and cost-effectiveness.

As part of this project, it was observed that soil texture (e.g. light-textured sandy soils) in some regions was the driving factor for using animal products to maintain soil health, structure and optimise use of water and fertilisers. The microbiological samples collected mainly from the baby leaf production soils did not show a major concern of pathogen survival, but the sampling from other cropping systems is continuing to generate a better understanding on this aspect.

At least 15 leafy vegetable growers have expressed interest in participating in a pilot study on the fate of pathogens in soils amended with different types of organic products. This study will generate the first dataset on the pathogen prevalence and distribution and their potential to contaminate produce in the real-world scenarios over multiple cropping seasons. Such longitudinal studies provide useful data and insights into the nature and magnitude of risks and help develop strategies to manage risks. A data-driven food safety management approach has proven powerful in several other industries, such as melons and citrus.

Soil health management is critical to supporting sustainable leafy vegetable production systems with safer amendment options such as certified composts or cover crops. However, the use of raw animal products requires proper risk assessment and management strategies to mitigate associated food safety risks. The data from the proposed pilot study will provide better understanding of risks and management strategies.

Coexistence of animals and horticultural industries and food safety management

Horticultural and animal industries have coexisted for centuries, but the risk of microbial contamination has lately amplified due to intensification of production systems, degradation of natural resources (soil and water), lengthy supply chains, produce consumption patterns and increased frequency and severity of extreme weather events. The animal operations have potential to contaminate water sources, produce, equipment, and premises.

Management of proper buffer zones to separate these operations and install hurdles to prevent airborne (e.g. wind breaks) and waterborne contamination (e.g. run-off control) are some of the practical and cost-effective measures. Proximity of leafy vegetable production fields to animal operations requires diligent risk



sheep grazing in leafy vegetable fields as a practice to utilise crop biomass as animal feed.

The exclusion periods applicable to raw manures should also be considered for animal grazing in leafy

production systems. The project has identified significant opportunities to improve these measures, especially in regions where livestock graze in vegetable fields postharvest.



Lettuce harvesting in progress

Extreme weather events

Extreme weather events are intensifying in frequency and severity. These include floods, heavy rainfall, droughts, dust storms, bushfires and heatwaves, all of which disrupt horticultural production and postharvest systems. While the direct impacts of such events on crop losses are widely recognised, their implications for microbial food safety—particularly in the fresh horticultural produce sector — remain less understood.

In this project, it has been examined how extreme weather events exacerbate microbiological contamination risks in leafy vegetable production systems. There is more work required to develop actionable strategies for risk mitigation and adaptation measures. As part of the recommendations to growers, adoption of climate-smart practices has been proposed to building resilience in the supply chain and safeguarding consumer health. Developing and maintaining an extreme weather events register is one of the strategies to manage risks based on records and subsequent remedial measures.

Harvest and postharvest cross-contamination risks



A project team member collecting microbiological swabs from plastic crate

Harvesting machinery and containers (bins and crates) have been identified as the potential routes of microbial cross-contamination in leafy vegetables. Cleaning and sanitising machinery and harvest containers after each shift/use is the basic requirement to manage these risks.

Postharvest washing and sanitisation processes offer huge opportunities for cross-contamination of leafy vegetables. Wash water quality, a lack of adequate sanitiser concentrations and recirculation of wash water are major risks identified in this project.

Triple wash system

The sanitisation flow during processing of leafy



Maintenance of appropriate sanitiser concentrations and frequency of wash water change are critical postharvest operations. It has been observed that triple wash systems in some processing facilities are being operated on a gradient of sanitiser concentration with the lowest or zero concentration in the first wash water tank and then higher concentrations in the second and third tanks. It is recommended that processors should review their sanitiser concentration gradient and the highest sanitiser concentration in the first tank is required to prevent cross-contamination and deal with higher organic load.

Food safety helpdesk

As part of this project, a food safety helpdesk service is available to all growers and supply chain partners to address their technical enquiries on food safety. This service has been popular with the industry to confidentially discuss their food safety concerns and find solutions. To access the helpdesk, contact SP Singh (details below).

Get involved

Over 80 leafy vegetable growers are engaging with this project to seek solutions to food safety process improvement and compliance issues. The project team is calling on growers and processors to participate in the project by sharing their food safety practices, be a part of the irrigation water quality or soil amendments trials and learn more about data-based food safety risk management. The project team maintains confidentiality and privacy of all participants, and presents and uses data in aggregated and anonymised form for industry-wide food safety practice improvement.

FOR MORE INFORMATION
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Related Projects

Identifying and managing the sources and routes of microbial contamination in leafy vegetables

This project has been funded by Hort Innovation, using the research and development levies listed below and contributions from the Australian Government. Hort Innovation is the grower-owned, not-for-profit research and development corporation for Australian horticulture.

- [Vegetable Fund](#)

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‘Mind the W’: bridging gaps in the production and supply of safe leafy vegetables

Words by Dr Sukhvinder Pal (SP) Singh, Dr Craig Shadbolt, Dr David Cusack and Dr Mark Turner

Leafy vegetables are a cornerstone of healthy diets, known for their rich nutritional profile and versatility in dietary options. Increasing the consumption of leafy vegetables plays an important role in both food security and public health. However, the very nature of leafy vegetables, which are often consumed raw or with minimal processing, are grown near the soil, and possess intricate surfaces, renders them inherently susceptible to microbial contamination. Recognising these vulnerabilities, robust microbial food safety risk management is not merely a regulatory obligation but a critical imperative for all stakeholders in the leafy vegetable supply chain.

This article considers key microbial risk factors and outlines comprehensive management strategies, emphasising the ‘Mind the W’ framework, a proactive approach to ensuring the safety of leafy vegetable products. This framework was developed as part of the Safe Leafy Veg program, co-funded by Hort Innovation and the NSW Government, and supported by the industry.

The ‘Mind the W’ framework: a holistic approach to risk management

Ensuring the microbial safety of leafy vegetables requires a multifaceted and integrated approach that addresses potential

contamination points throughout the entire production and postharvest operations. Effectively communicating scientific knowledge and translating it into best practice remains a persistent challenge in food safety systems. The proposed framework is specifically designed to simplify and streamline communication, using clear and accessible language to maximise the likelihood of best practice adoption by leafy growers and processors (Figure 1).

The ‘Mind the W’ framework offers a structured yet flexible methodology, categorising critical risk areas under seven key ‘Ws’:

- Water-preharvest and postharvest
- Waste from animal operations
- Wildlife and animal incursions
- Wind from animal operations
- Weather extremes
- Washing and sanitisation
- Workers’ health and hygiene.

This framework is based on the understanding that these areas are interconnected, necessitating a holistic strategy where controls in one area complement and reinforce those in others. Effective risk management is not about isolating these factors but rather understanding their interplay and implementing a synergistic suite of preventative controls. Each ‘W’ represents a potential vulnerability, and a failure to address any one can compromise the entire food safety system.

Water

Water represents one of the most significant conduits for microbial contamination. Surface water sources such as rivers and creeks are commonly used for irrigation (Figure 2). Contaminated surface water, particularly when applied through overhead irrigation, can directly introduce a wide array of human pathogens to crops (Figure 3). Sources of contamination for horticultural water are diverse, including runoff laden with animal faeces, discharge from septic systems, and the presence of wildlife in water bodies. Pathogens can persist in water and adhere to plant surfaces, posing a direct threat to human health upon consumption.

Effective water management strategies begin with a rigorous source water assessment. Surface water quality deteriorates in the summer months and after heavy rainfall or flooding events. Growers should regularly test their water sources (eg. rivers, ponds, borewells) to understand their microbial profile and potential for contamination. Adherence to strict water quality standards is paramount; for instance, irrigation water for leafy vegetables should meet specific microbial criteria, such as *E. coli* levels below 100 colony-forming units (CFU) per 100mL, as per quality assurance guidelines. The probability of pathogen detection increases with the increase in *E. coli* population



Figure 1: Mind the W— a risk communication and management framework proposed for adoption by the leafy vegetable industry.

(>100 CFU/100mL) in surface water.

Comprehensive monitoring programs with routine testing schedules are essential for tracking water quality fluctuations. Beyond testing, proactive measures like managing sediment in surface water, which can harbour and protect microorganisms, are crucial. Overhead irrigation of leafy vegetables within 48 hours of harvest requires water quality that is closer to potable. Where feasible in some crops, transitioning from overhead irrigation to methods like drip or subsurface irrigation minimises direct contact of water with the edible portions of the plant. For high-risk water sources, treatment options such as filtration, UV treatment, or controlled chlorination or ozonation may be necessary to reduce microbial loads.

Waste from animal operations

The use of organic soil amendments,

particularly animal faecal waste, presents a considerable risk if not managed correctly. Contaminated faecal material, whether applied as raw manure or inadequately composted products, can introduce pathogens to the soil and subsequently to crops. Pathogens such as *E. coli* and *Salmonella* can survive in the soil for extended periods, leading to direct contamination through splash, dust, or indirect transfer via equipment.

Mitigation focuses on strict protocols for composting and application of these amendments, with thorough microbiological risk assessment. Proper composting methods, involving controlled temperature and turning regimens, are critical to achieving pathogen reduction. Validated composting processes that reach specific time-temperature combinations are essential. All soil amendments, even composted materials, must be stored and handled appropriately to

prevent cross-contamination with crops, equipment, or water sources. Documentation of the source, treatment, and application dates of all soil amendments is vital for traceability and risk assessment.

Wildlife and animal incursions – uncontrolled contamination sources

The presence of wildlife and domestic animals in or near leafy production areas represents an uncontrolled source of microbial contamination. Animals, through their faeces, can introduce a variety of pathogens directly onto crops or into the soil. Postharvest livestock grazing in or near fields can also lead to significant contamination risk for subsequent crops to be grown.

To mitigate this risk, exclusion measures are paramount. Physical barriers such as fencing and netting can deter larger animals, while rodent control programs address smaller pests. Habitat management is also crucial; removing attractants like food waste, standing water, and overgrown vegetation around fields and facilities reduces the likelihood of animal presence. Growers must conduct diligent pre-harvest field assessments, visually inspecting for signs of animal intrusion and fresh faecal matter. Any contaminated areas necessitate the establishment of harvest exclusion zones. Furthermore, managing livestock activities, preventing grazing near leafy fields, and controlling runoff from adjacent animal operations are vital. Finally, thorough worker training in identifying and reporting signs of animal intrusion ensures a proactive response to potential contamination.

Animal operations – airborne contamination

Wind is an often-underestimated vector for microbial contamination, particularly when leafy vegetable production areas are in proximity to intensive livestock operations such as feedlots, poultry farms or dairies. Pathogen-laden dust and aerosols originating from animal faeces or dry manure piles can be carried

by wind over significant distances, settling on growing crops or entering open packing facilities. This airborne transfer bypasses many traditional control measures, posing a unique challenge.

Mitigation strategies for wind-borne contamination primarily focus on strategic selection of location and the establishment of physical barriers. Growers should prioritise growing leafy greens in locations geographically distant from high-risk animal operations. Establishing and maintaining adequate physical separation through buffer zones between fields and animal facilities, including areas where animal waste is stored, are crucial. The strategic planting of perennial windbreaks (eg. trees, shrubs) can significantly reduce the impact of wind-borne dust and aerosols.

Weather extremes – exacerbating pathogen transfer

Extreme weather events (eg. heavy rainfall, flooding, dust storms or bushfires) and other natural disasters can severely compromise food safety. Flooding poses an immediate risk, as contaminated water from diverse sources, including manure lagoons, septic systems, and fields with high wildlife activity, can inundate growing areas and even processing facilities. Such events facilitate the widespread transfer of pathogens, rendering affected crops unsafe for consumption. Similarly, heavy rainfall can lead to increased runoff and splash contamination, dispersing pathogens across fields. Conversely, prolonged drought conditions can result in increased dust, which, if contaminated with faecal matter, can become an airborne vehicle for pathogen dissemination.

Effective management requires pre-emptive planning, including the development of robust emergency response plans for weather events. These plans should detail post-flood assessment protocols, including visual inspections and microbial testing of soil and produce. Establishing clear exclusion zones



Figure 2: On-farm dam used for storing irrigation water, generally pumped from surface water sources such as rivers and creeks.

for harvesting crops from flooded areas is critical. Furthermore, comprehensive documentation of weather events and their potential impact on specific fields is essential for risk management. Infrastructure resilience, such as improved drainage systems and field layouts designed to minimise flood impact, can also significantly reduce risk.

Washing and sanitisation – preventing cross-contamination

Washing and sanitisation steps are critical in postharvest handling, but if not managed, they can also inadvertently become sources of cross-contamination (Figure 4). Inadequate sanitiser concentration or insufficient replenishment of wash water can allow pathogens from a few contaminated leaves to spread to an entire batch of otherwise clean produce. Biofilm formation in wash systems, where microorganisms can adhere to surfaces and resist sanitation, is another significant challenge. The complex, often wrinkled surfaces of leafy greens make effective pathogen removal particularly difficult.

Therefore, stringent control of wash water quality is essential. Only potable water (eg. *E. coli* < 1 CFU/100 mL) should be used for the wash step. The selection and management of approved sanitisers (eg. chlorine,

peracetic acid) are critical, requiring careful attention to their efficacy, optimal concentration, and factors affecting their performance, such as pH, organic load, and temperature. Protocols for sanitiser concentration monitoring, timely water replenishment and proper management of recirculated wash systems are crucial to prevent the build-up of microbial loads. These protocols should allow increasing sanitiser concentrations and water replenishment rates when higher microbial and organic loads are expected on leafy vegetables due to extreme weather conditions such as heavy rainfall and dust storms. Furthermore, robust cleaning and sanitisation programs for all washing, sorting, and packing equipment are vital to prevent biofilm formation. All washing and sanitisation processes should be validated and verified to ensure their proven efficacy in pathogen reduction.

Workers' health and hygiene

Human handling is a key point of potential contamination in leafy vegetable production and postharvest handling. Ensuring that all workers are in good health, understand the risks they may pose to food safety, and adhere to strict hygiene practices is essential for minimising microbial hazards. This includes regular health screening,

proper handwashing techniques, access to clean sanitation facilities, and the use of appropriate protective clothing. Ongoing training and a culture of accountability further empower workers to take ownership of their role in maintaining food safety. By prioritising worker health and hygiene, the framework supports a proactive approach to preventing contamination and ensuring a safer supply of leafy vegetables.

Implementing the ‘Mind the W’ framework through the Safe Leafy Veg program

The microbial safety of leafy vegetables is a complex challenge, yet one that can be effectively managed through diligence and adherence to evidence-based best practice. The ‘Mind the W’ framework provides a clear and actionable guide for addressing the seven critical risk areas. It is abundantly clear that no single control measure is sufficient. This integrated system ensures that multiple layers of protection are in place throughout the production and postharvest chain, significantly reducing the likelihood of microbial contamination. By embracing these principles, we can protect public health, maintain consumer confidence, and ensure the continued enjoyment of safe and nutritious leafy vegetables.

Dr Sukhvinder Pal (SP) Singh is a Senior Research Scientist at the NSW Department of Primary Industries and Regional Development (NSW DPIRD) and leads the Safe Leafy Veg project as part of the Fresh Produce Safety and Traceability program.

Dr Craig Shadbolt is a Principal Research Scientist at the NSW DPIRD with extensive expertise in foodborne illness investigations and risk assessment.

Dr David Cusack is the Manager of Food Standards and Programs at the NSW DPIRD. He is currently chairing the Horticulture Standards Implementation Working Group.

Dr Mark Turner is Professor of food microbiology from the School of Agriculture and Food Sustainability at



Figure 3: Overhead sprinkler irrigation in a baby spinach production field.



Figure 4: Washing and sanitisation of mixed-leaf salad.

The University of Queensland. He is a key collaborator on the Safe Leafy Veg project, contributing genomics insights to pathogen transmission.

For further information on the Safe Leafy Veg program, contact Dr S.P. Singh at: sp.singh@dpiird.nsw.gov.au or 0420 593 129. 

Acknowledgement

This project (VG22002) has been funded by Hort Innovation using the vegetable research and development levy and funds from the Australian Government, as part of the Vegetable Investment program. More information on the fund and strategic levy investment can be found at: <https://www.horticulture.com.au/>

SAFE LEAFY VEG

‘Mind the W’ Framework



Leafy vegetables such as lettuce, spinach and herbs are often eaten raw or only lightly processed. Because they grow close to the soil and have complex leaf surfaces that can easily shelter microorganisms, they're especially vulnerable to contamination. With no cooking or kill step before they reach consumers, preventing pathogen transmission becomes critical.

Words Sukhvinder Pal (SP) Singh, Senior Research Scientist, NSW Department of Primary Industries and Regional Development; Joel Dinsdale, Quality Assurance Coordinator, vegetablesWA; and, Chris Hall, Total Quality Assurance Systems, WA

TO help growers manage these risks more effectively, the ‘Mind the W’ framework has been developed through the Safe Leafy Veg program, co funded by Hort Innovation and the NSW Government and supported by industry — to turn scientific insights into practical, on farm risk management strategies (Singh et al., 2025).

Pathogen transmission in leafy vegetables typically originates from faecal sources and occurs through environmental pathways.

Key hazards include pathogenic *E. coli*, *Salmonella* and *Listeria monocytogenes*. These can reach crops through contaminated water, poorly treated manures, wildlife intrusion, windborne dust, flooding, cross contamination during washing, or inadequate worker hygiene.

Because these pathways are so varied and interconnected, a systems based approach is essential. The ‘Mind the W’ framework groups risks into seven linked domains (see Figure 1).

Water, **Waste** from animal operations, **Wildlife** and animal incursions, **Wind** from animal operations, **Weather** extremes, **Washing** and sanitisation, and **Workers’** health and hygiene. Together, they provide a structured and flexible method for proactive risk management.



Surface water sources (e.g. soak) are prone to microbial contamination due to livestock operations in the catchment area.

to contamination from livestock runoff, wildlife activity and weather events. When used for overhead irrigation, water comes into direct contact with edible plant surfaces. Research from the Safe Leafy Veg program shows that even water meeting irrigation guidelines (*E. coli* < 100 CFU/100 mL) can carry bacterial pathogens, with detection rates rising sharply above this threshold. Regular monitoring for indicator organisms like *E. coli*, combined with catchment level assessments and multi year trend data, is essential. Where risks are elevated, treatment options such as sedimentation, filtration, UV or controlled chlorination may be required.

Water quality often declines after heavy rain, flooding or during warmer months, especially in dams, soaks and rivers. Summer testing frequently reveals adverse results in rainwater tanks as well. However, some operators choose to pump dam water into storage tanks to supplement supply. This practice poses a significant risk because it can introduce pathogens from surface water into on site storage tanks. Whole genome sequencing from the Safe Leafy Veg program confirmed that contamination was transferred from farm dams into rainwater tanks.

Because tank water is routinely used for washing produce and for handwashing, maintaining high microbiological quality is critical. Untreated surface water should not be used to top up tanks, and tanks should be cleaned and flushed on a preventative schedule, ideally at least annually, and more often where risks exist, alongside regular sanitiser dosing. Postharvest wash water must meet potable standards (*E. coli* < 1 CFU/100 mL) and contain an effective sanitiser to prevent cross contamination.

Waste from animal operations, particularly manure-based soil amendments, presents another significant risk if not properly managed. Pathogens can persist in soil for long periods and easily move onto crops through splash, dust,



FIGURE 1. Mind the W Framework

Source: Adapted from Singh et al., 2025

Water is a major pathway for microbial contamination in leafy vegetables. Surface water sources such as rivers, dams, creeks, and soaks, are dynamic and vulnerable

or contaminated equipment. Using validated composting processes that reach the right time-temperature combinations is essential for reducing these risks. Just as important are proper storage practices, clear documentation of amendment sources and application dates, and measures that prevent cross contamination between compost, crops and equipment.

Wildlife and animal incursions are unpredictable and can be major sources of contamination. *Salmonella* is frequently isolated from native wildlife, including quokkas, kangaroos and wallabies. In kangaroos, *S. Muenchen* and *S. Typhimurium* are commonly reported, while *S. Typhimurium* predominates in wallabies. In quokkas, *S. Muenchen*, *S. Adelaide* and *S. Wandsbek* are frequently detected, and *S. Rubislaw* is typically associated with reptiles. Whole genome sequencing from the Safe Leafy Veg project also showed that detections of *S. Muenchen* and *S. Rubislaw* were linked with wildlife activity on vegetable farms and in packing sheds.

Wild and domesticated animals may deposit faeces directly in fields, contaminating soil, produce, irrigation water and packing areas. Where intrusion or faecal contamination occurs, exclusion zones should be established and affected produce withheld from harvest. Mitigation measures include fencing, netting, rodent control, habitat management and thorough pre harvest inspections. Strong worker awareness and training support timely detection and response. Postharvest facilities should also be managed to keep out pets and wildlife such as marsupials, rodents and reptiles.

Wind is a less visible but significant transmission pathway, especially when leafy vegetable fields are located near intensive livestock operations. Dust and aerosols carrying pathogens can travel long distances and settle on crops or enter open packing sheds. Strategic site selection, buffer zones and vegetative windbreaks help reduce airborne contamination risks. Understanding the broader landscape and neighbouring land uses is therefore key to managing microbial hazards.

Weather extremes such as flooding, heavy rainfall, drought, dust storms and bushfires can amplify contamination risks. Flooding can bring contaminated water directly into production areas, often making crops unsafe for harvest (Singh, 2023). Heavy rainfall increases runoff and splash dispersal of pathogens, while drought and dust storms promote airborne contamination. Bushfires may displace wildlife, which, in search of shelter, water or food, can enter fields and water sources and contaminate produce. Effective management requires pre-emptive planning, post-event assessments, clear documentation of weather impacts and, where needed, harvest exclusion zones.

Washing and sanitisation are critical control points in postharvest handling, but can themselves become sources of cross-contamination if poorly managed. Inadequate

sanitiser concentrations, high organic loads or insufficient water replacement can allow pathogens to spread from a small number of contaminated leaves to an entire batch. Potable wash water, careful monitoring of sanitiser efficacy, and validated cleaning programs are essential. Equipment should be routinely cleaned and sanitised to prevent biofilm formation. Washing reduces microbial load but does not eliminate all pathogens, reinforcing the need for strong upstream controls.

Workers' health and hygiene remain fundamental to food safety. Human handling during harvesting and processing can introduce contamination, if proper hygiene practices are not followed. Access to handwashing facilities, illness reporting procedures, appropriate protective clothing and regular training, are critical components of a strong food safety culture. Empowering workers to recognise risks and take ownership of preventive actions strengthens the entire system.

The 'Mind the W' framework underscores that no single control is enough. Each "W" is a potential risk point, and weakness in one can affect the rest.

Effective risk management depends on multiple, consistent layers of protection across preharvest and postharvest activities. This integrated, science-based approach helps reduce pathogen risks and maintain safe, reliable produce. Food safety relies on systems thinking, continual monitoring and shared responsibility. **WAG**

Acknowledgment

This project (VG22002) has been funded by Hort Innovation using the vegetable research and development levy and funds from the Australian and NSW Governments. For further information on the Safe Leafy Veg program, contact Dr S.P. Singh at sp.singh@dpi.nsw.gov.au or 0420 593 129.

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AUSTRALIAN GROWER

2024 SPRING

VEGETABLES / ONIONS / POTATOES

GROWER PROFILE | R&D CASE STUDY

VEGETABLES

While it's still early days, Maureen strongly encourages other growers to participate in the research and see a return on their levy investment.

Identifying and managing the sources and routes of microbial contamination in leafy vegetables (VG22002) is led by Sukhvinder Pal Singh (better known as SP) from the New South Wales Department of Primary Industries. It will work closely with leafy vegetable growers and processors to gain deeper insights into sources and routes of contamination and identify ways to disrupt the transmission of these pathogens into the supply chain.

The project will use a multi-pronged approach that involves engaging growers, benchmarking industry practices, identifying gaps in food safety management and promoting the adoption of best management practices to address any risks proactively.

"They've done some soil tests and water tests for us. It's actually been very good because it's focused on our water quality and what we can do to improve it," Maureen said.

"We've also discussed putting more trees or shrubs on our boundaries to stop sand from other properties blowing onto the farm and bringing in weeds from the seed in the sand."

Maureen is also proactively considering dam covers to prevent access by bird life, which she has discussed with her grower network on the east coast.

As the Loose Leaf Lettuce Company is certified by Freshcare Food Safety and Quality and Hazard Analysis and Critical Control Point (HACCP), quality assurance is a crucial arm of the business.

"Water contamination is critical to manage. I've read issues in the United States and obviously in Australia with melons and leafy greens, so we are trying to stay aware of the issues. Talking to SP is great," Maureen said.

While it's still early days, Maureen strongly encourages other growers to participate in the research and see a return on their levy investment.

"The more knowledge you have, the better off you are – even if it's just about developing your networks."

The project Vegetable industry communications program has been funded by Hort Innovation, using the vegetable research and development levies and contributions from the Australian Government. Hort Innovation is the grower-owned, not-for-profit research and development corporation for Australian horticulture.
Project: VG22000

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Leafy Veg**

Food safety management statement (FSMS) 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, postharvest 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 growers 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. Growers 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 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 activity scope covered by the certification:

☐ Leafy vegetables (iceberg lettuce, baby spinach): _____
☐ 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

Tick all that apply.

- ☐ 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)
- ☐ Soilless production (e.g. hydroponic) in open
- ☐ Soilless production (e.g. hydroponic) under cover (partially enclosed structures)
- ☐ Soilless 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 covered by this FSMS

Tick all activities undertaken by the business.

1.8.1 Production activities

- ☐ Growing
- ☐ Harvesting

1.8.2 Postharvest activities

- ☐ Field packing
- ☐ Trimming and cutting
- ☐ Washing
- ☐ Washing and sanitising
- ☐ Cooling
- ☐ Cold storage
- ☐ Packing
- ☐ Repacking
- ☐ Storage
- ☐ Distribution
- ☐ Transport
- ☐ Other postharvest 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 product 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 Product 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 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 Product recall

Does your business have a documented product 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 water source for each

- ☐ Irrigation (e.g. river)
- ☐ Fertigation/hydroponics (e.g. rainwater)
- ☐ Agricultural chemical application (e.g. farm pond sourced from river)
- ☐ Frost and heat protection (e.g. groundwater)
- ☐ Postharvest 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)
- ☐ Before each crop cycle
- ☐ Following significant rainfall or flooding
- ☐ No testing conducted
- ☐ No testing 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
- ☐ 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 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 postharvest 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.

- ☐ Product 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?

- ☐ Product 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 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 microbiological 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 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 is 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 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 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 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 postharvest equipment for potential contamination risks?

- ☐ Yes
- ☐ No

Identify 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 sanitisation 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 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 postharvest 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: _____

Postharvest equipment cleaning and sanitisation 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 sanitisation 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 product 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 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 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, product 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 worker 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
- ☐ Product traceability and recall procedures
- ☐ Identification and management of unacceptable product
- ☐ 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 area
- ☐ 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 product

10.1. How do you identify an unacceptable product?

- ☐ 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 product 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