

SAAFE^{CRC}

**Research
Report**

SAAFE Project: 2_P012

Hort Innovation Project: VG23004

**Risk assessment of
antimicrobial
resistance in the
vegetable industry**

Research & Funding Acknowledgements

We would like to formally acknowledge the growers, industry representatives and technical experts who contributed to this project through surveys, consultation and review. Some have chosen not to list their names or affiliations, but we thank all equally.

The views expressed in this report, the associated factsheets and supporting documents are the views of the paper's authors or participants, and do not necessarily reflect the views of Hort Innovation, SAAFE CRC, or the organisations the project team members work for.

This project (Hort Innovation VG23004) was funded using the vegetable research and development levy, with co-investment from by the Solving Antimicrobial Resistance in Agribusiness, Food, and Environments Cooperative Research Centre whose activities are funded by the Australian Government's Cooperative Research Centre Programme. This is SAAFE CRC Publication P012_PB003.

Project Team and Authors:

A/Prof Barbara Drigo, School of Agriculture, Food and Wine, Adelaide University

Prof Nicholas J. Ashbolt, School of Civil and Environmental Engineering, Queensland University of Technology

Dr. Jowenna Xiao Feng Sim, School of Agriculture, Food and Wine, Adelaide University

Suggested citation:

Drigo, B., Sim, J.X.F., Hayward, C., Ashbolt, N.J., Drew, M. (2026). Risk assessment of antimicrobial resistance in the vegetable industry. Prepared for Hort Innovation, SAAFE CRC Publication number P012_PB003.

MS190 Final Report

Project title:

Risk assessment of antimicrobial resistance in the vegetable industry

Project leader:

A/Prof Barbara Drigo

Delivery partner:

Cooperative Research Centre for Solving Antimicrobial Resistance in Agribusiness, Food, and Environments

Report author/s:

A/Prof Barbara Drigo, School of Agriculture, Food and Wine, Adelaide University

Dr. Jowenna Xiao Feng Sim, School of Agriculture, Food and Wine, Adelaide University

Dr. Claire Hayward, SAAFE^{CRC}, Future Industries Institute, Adelaide University

Dr. Mark Drew, Gandhara Consultancy Pty Ltd

Project code: VG23004

Date: 01 August 2026

Report sensitivity:

Does the report have any of the following sensitivities?

Commercialization/IP considerations: No

Intended for journal publication: Yes

Embargo date: Yes – Date: 31 Dec 2026

Reason for embargo: The peer-reviewed journal manuscript arising from this project is currently accepted. Publication is anticipated before December 2026. An embargo is requested to protect the originality of the research and to avoid potential conflicts with the journal's publication requirements.

Confidentiality: Yes (sections of report are confidential)

If sections of the report are confidential, list them here: The sections listed as confidential are included in the MS190 Final Report Appendix file attached to this report.

Disclaimer:

Horticulture Innovation Australia Limited (Hort Innovation) makes no representations and expressly disclaims all warranties (to the extent permitted by law) about the accuracy, completeness, or currency of information in this final report.

Users of this final report should take independent action to confirm any information in this final report before relying on that information in any way.

Reliance on any information provided by Hort Innovation is entirely at your own risk. Hort Innovation is not (to the extent permitted by law) responsible for, and will not be liable for, any loss, damage, claim, expense, cost (including legal costs) or other liability arising in any way (including from Hort Innovation or any other person's negligence or otherwise) from your use or non-use of the final report or from reliance on information contained in the final report or that Hort Innovation provides to you by any other means.

Funding statement:

Levy funds – R&D projects

This project has been funded by Hort Innovation, using the <insert industry> research and development levy and contributions from the Australian Government. Hort Innovation is the grower-owned, not-for-profit research and development corporation for Australian horticulture.

Publishing details:

ISBN <Hort Innovation to add>

Published and distributed by: Horticulture Innovation Australia Limited
ABN 71 602100149

Level 7
141 Walker Street
North Sydney NSW 2060

Telephone: (02) 8295 2300

www.horticulture.com.au

© Copyright 2026 Horticulture Innovation Australia Limited

Contents

Public summary	4
Technical summary	4
Keywords	5
Deliverable 1.....	5
Introduction.....	5
Rationale.....	5
Methodology	5
Results Summary	6
Outputs/Communications	7
Deliverable 2.....	8
Introduction.....	8
Rationale.....	8
Results Summary	12
Outputs/Communications	13
Deliverable 3.....	14
Summary.....	14
Introduction.....	14
Methodology	14
Results and discussion	14
Outputs.....	17
Output summary.....	17
Photos/images/other audio-visual material (see appendix for more pictures)	19
Outcomes.....	20
Outcome summary	20
Recommendations.....	23
Referred scientific publications	26
Journal article	26
Intellectual property	26
Acknowledgements	26

Public summary

Antimicrobial resistance (AMR) is recognised as one of the most significant global challenges affecting human, animal, plant, and environmental health. AMR occurs when microorganisms develop resistance to treatments that had previously been effective, reducing the ability to prevent and control infectious diseases. In addition to its impacts on human health, where antimicrobial-resistant infections contribute to more than 1,000 deaths annually in Australia, AMR also poses risks to agricultural productivity, food security, biosecurity, and environmental sustainability. The emergence of resistant plant pathogens reduces the effectiveness of disease management practices and has the potential to affect crop productivity, market access, and consumer confidence. Although the use of antimicrobials and pesticides in Australian agriculture is regulated, the relationship between agricultural practices and the development of resistance remains incompletely understood.

This project investigated the occurrence, drivers, and potential impacts of AMR across the Australian vegetable supply chain, from primary production through to post-harvest handling. The project assessed the relative risks associated with key production practices, including the use of seeds and seedlings, irrigation water, soils, crop protection practices, and post-harvest operations, while considering the influence of different production systems and environmental conditions.

The project developed the first evidence-based screening-level risk assessment for Australia's levy vegetable industries, identifying the production stages and practices that contributed most significantly to AMR risks. The findings highlight priority areas where targeted interventions could reduce the emergence and spread of antimicrobial and agrochemical resistance and improve food safety outcomes. The project also provided practical guidance to support the adoption of science-based risk management practices by vegetable growers and industry stakeholders. Collectively, the project outcomes strengthened the evidence base for future research, extension, and policy development, contributing to a more resilient, sustainable, and biosecure Australian vegetable industry and supporting the objectives of the Vegetable Strategic Investment Plan 2022–2026.

Technical summary

Antimicrobial resistance (AMR) is recognised as one of the most significant emerging threats to human, animal, plant, and environmental health. Within horticultural production systems, AMR encompasses both antimicrobial-resistant microorganisms that pose food safety risks and agrochemical-resistant plant pathogens that compromise crop protection. The emergence and spread of resistance reduce the effectiveness of disease management practices, increase production costs, and create potential risks to food safety, market access, trade, and the long-term sustainability of vegetable production. Fresh and minimally processed vegetables are of particular concern because they are commonly consumed raw and may provide a pathway for the transmission of antimicrobial-resistant microorganisms and resistance genes to consumers. This project investigated the occurrence, drivers, and relative risks of AMR across Australian vegetable supply chains, with a particular focus on the three priority levy crops: leafy greens, cucumbers, and carrots. Production systems were examined from pre-production through to post-harvest handling to identify factors influencing both human health risks associated with extended-spectrum beta-lactamase (ESBL)-producing *Escherichia coli* and plant health risks associated with agrochemical resistance. Data from Australian grower surveys and published literature were integrated into a semi-quantitative, screening-level risk assessment (SLRA) tailored to Australian vegetable production systems. A quantitative Monte Carlo simulation framework was developed to evaluate six crop–pathogen scenarios. For each crop, two complementary models were constructed: a human health model describing the movement of ESBL-producing *Escherichia coli* through the supply chain and a plant health model evaluating pathogen population dynamics and resistance selection standard production practices. Model parameters were derived from published scientific evidence, Australian industry and grower survey data, and author estimates. Sensitivity analyses were undertaken to identify the production stages and management practices contributing most significantly to overall risk. Across all six scenarios, the SLRA consistently demonstrated that pre-production and early production practices were the primary determinants of AMR risk. Seed and seedling quality, nursery management, irrigation water quality, soil characteristics, and other primary production inputs

exerted substantially greater influence on both human and plant health risks than downstream interventions. Once resistant microorganisms or pathogen populations became established during the early stages of production, subsequent chemical treatments and post-harvest management had limited capacity to substantially alter the overall risk profile. This project delivered the first integrated, evidence-based SLRA for evaluating AMR across Australian vegetable supply chains. The findings identified critical control points where targeted interventions are most likely to reduce AMR risks and provide a robust scientific foundation for future research, industry extension, and policy development. By supporting risk-based decision-making and promoting improved management of microbial and agrochemical resistance, the project strengthens food safety, biosecurity, sustainable production, and long-term industry resilience. These outcomes directly support the priorities of the Vegetable Strategic Investment Plan 2022–2026 by enhancing industry capability, encouraging the adoption of evidence-based management practices, and strengthening consumer confidence in Australian-grown vegetables.

Keywords

Antimicrobial resistance; Australian vegetable industry; Food safety; Risk assessment; Ready-to-eat vegetables; Agrochemical resistance.

Deliverable 1

Introduction

Antimicrobial resistance (AMR) is recognised globally as a major One Health challenge affecting human, animal, plant, and environmental health. Within horticultural production, resistance to fungicides and bactericides threatens crop productivity, food security, market access, and the long-term sustainability of disease management practices. Although Australia has well-established regulatory controls governing the use of agricultural chemicals, there is limited consolidated information describing the occurrence and distribution of fungicide and bactericide resistance in vegetable pathogens affecting Australian levy crops. Deliverable 1 addresses this knowledge gap by reviewing documented evidence of antimicrobial resistance in major vegetable production systems, including leafy vegetables, brassicas, carrots, cucurbits, and other economically important crops. The review forms part of the Hort Innovation and Cooperative Research Centre for Solving Antimicrobial Resistance in Agribusiness, Food and Environments (SAAFE^{CRC}) project and provides the first comprehensive assessment of published and industry-derived evidence of resistance in Australian vegetable production. The findings establish a scientific baseline for resistance surveillance, risk assessment, stewardship, and future industry decision-making.

Rationale

The Australian vegetable industry contributes more than AUD \$6 billion annually to the national economy and relies heavily on effective disease management to maintain crop productivity, food quality, and domestic and international market access. The emergence of fungicide and bactericide resistance reduces the effectiveness of available crop protection products, increases production costs, and limits disease management options for growers. Despite the economic importance of vegetable production, Australia lacks a coordinated national surveillance program for AMR in vegetable pathogens, and existing information is fragmented across scientific publications, industry reports, and expert knowledge. Deliverable 1 was undertaken to consolidate these diverse information sources into a single evidence base that identifies documented cases of resistance, evaluates pathogen and fungicide risks, and highlights critical knowledge gaps. The review provides the foundation for developing evidence-based stewardship strategies, informing future surveillance programs, supporting industry extension activities, and strengthening the resilience and sustainability of Australian vegetable production against emerging AMR threats.

Methodology

A comprehensive review was undertaken to identify documented cases of AMR, specifically fungicide and bactericide resistance, in plant pathogens affecting Australian levy vegetable crops. The review combined published scientific literature,

industry knowledge, professional networks, and expert consultation to provide the most complete assessment of resistance records available. A systematic literature review was conducted using the University of South Australia library databases and Google Scholar. Searches employed combinations of the terms fungicide resistance, bactericide resistance, individual crop names, and Australia. In addition to peer-reviewed publications, resistance information and guidance published by the Fungicide Resistance Action Committee (FRAC) and CropLife Australia's Expert Committee on Fungicide Resistance (ECFR) were reviewed. These resources provided internationally recognized information on pathogen resistance risks and resistance management strategies relevant to Australian vegetable production. To capture unpublished industry knowledge, CropLife Australia was invited to participate in the review. CropLife circulated a short survey to members of its ECFR, requesting information on confirmed cases of fungicide and bactericide resistance in Australian vegetable pathogens. Industry feedback provided valuable insights into resistance issues identified through commercial crop production and product performance. The Australasian Plant Pathology Society (APPS) was also engaged to obtain information from researchers involved in resistance monitoring and diagnostic testing. Society members working in vegetable pathology were invited to complete a survey identifying published and unpublished records of antimicrobial resistance in vegetable crops.

Finally, informal consultations were conducted with experienced Australian plant pathologists who were currently or previously involved in fungicide and bactericide resistance testing and monitoring. These discussions helped identify additional records, historical observations, and unpublished information that may not have been captured through the literature or survey responses. The integration of evidence from scientific publications, industry surveys, professional organizations, and expert consultation provided a robust evidence base for assessing the occurrence of fungicide and bactericide resistance in Australian levy vegetable crops and identifying current knowledge gaps requiring future investigation.

Results Summary

The literature survey identified 15 papers and articles reporting reduced sensitivity or resistance to bactericides or fungicides in Australian levy vegetable crops (Table 5 Appendix 1A). Seven of these reports are referenced by CropLife in a list of plant pathogens and fungicide groups for which resistance or reduced sensitivity has been confirmed or suspected under Australian field conditions as of June 2024 (<https://www.croplife.org.au/resources/programs/resistance-management/fungicide-resistance-management-strategies/>). To manage the development of resistance, all fungicide products sold in Australia are classified according to the chemical activity group of their active constituent by an alphanumeric code on the product label; the industry recommends a range of strategies on product labels and through various stewardship programs to manage resistance (<https://www.croplife.org.au/resources/programs/resistance-management/fungicide-activity-group-table/>).

The ECFR is linked to a global FRAC which operates under the auspices of CropLife International (<https://croplife.org/>). FRAC and ECFR have each published lists of plant pathogens and their risk of developing fungicide resistance based on information from international markets (<https://www.frac.info/media/qluf3unn/frac-pathogen-list-2019.pdf>; <https://www.croplife.org.au/resources/programs/resistance-management/fungicide-resistance-management-strategies/>). Inherent pathogen risk of developing resistance is related to disease epidemiology, field disease management, and genetic factors. Pathogens with a short life cycle, high spore generation, high spore mobility, and mutation rates are among the inherent pathogen characteristics that favour the development of resistance. FRAC only rates pathogen risk as medium to high if resistance to more than one fungicide class has been reported in commercial use over the last 50 years. Pathogens of Australian levy vegetables identified in these lists as having a medium or high risk of development of resistance are shown in Table 6 (Appendix 1A).

The inherent fungicide resistance risk can be gauged by considering the chemical structure and mode of action of a particular fungicide, with each chemical class characterised by a resistance behavior profile. This profile allows predictions to be made regarding the propensity of specific fungicides to select for resistance in target pathogens and new pathogens (Brent and Hollomon, 2007, pp. 6–11). Fungicide groups considered to have a high or medium-to-high risk of developing resistance are shown in Table 7 (Appendix 1A).

To estimate the risk of a particular fungicide selecting for resistance and to assist in developing strategies to delay selection for, or to manage, resistance, FRAC has developed a risk matrix based on inherent fungicide and pathogen risks, incorporating agronomic risk associated with the crop/pathogen interface (<https://www.frac.info/media/qluf3unn/frac-pathogen-list-2019.pdf>). Applying this rubric, total risk is calculated by multiplying the relevant variables together (Table 8, Appendix 1A).

Agricultural chemicals industry

CropLife circulated a short survey to the ECFR asking members to report known instances of bactericide or fungicide resistance which they had recorded. This initial communication was followed by several prompts for recipients to respond. Unfortunately, only one member of the 10 contacted returned the completed survey; the sole respondent was not able to report any cases of fungicide resistance.

Public sector researchers

Unfortunately, the request to APPS was declined, potentially limiting the scope of responses to the review.

Plant pathologists involved in resistance testing or monitoring

Several plant pathologists currently or previously involved in the broader field of fungicide or bactericide resistance testing or monitoring in Australia were identified. Discussions were held with these individuals with the aim of identifying plant pathologists currently or previously involved in testing for AMR in vegetable pathogens in Australia who might have records of resistance which have not been published. The individuals contacted could not identify any plant pathologists currently involved with monitoring or testing pathogens of Australian levy vegetable crops for bactericide or fungicide resistance.

This review indicates that the publicly available information regarding evidence of antimicrobial resistance in Australian levy vegetables is not current and is difficult to access. Additionally, the review identifies that members of the Australian agrochemicals industry, which should be at the forefront of bactericide and fungicide resistance monitoring, detection and recording, are loath to discuss their individual experiences and records. This latter situation may exist because of the commercial sensitivity of publicising the detection of resistance to proprietary molecules and the impact this could have on an individual company's sales.

The review also identifies that there is a lack of resources currently applied by, or available in the public sector for monitoring and testing for bactericide and fungicide resistance in levy vegetable crops in Australia. This contrasts with other sectors of the agricultural economy. For example, in the Australian broadacre cropping sector (canola, cereal, and pulse crops) fungicide resistance in key pathogens is considered to pose a significant threat to production. In response, the industry has established the Australian Fungicide Resistance Extension Network (AFREN; <https://afren.com.au/>), a network of plant pathologists, fungicide resistance experts, and extension specialists formed to address AMR in this sector. AFREN regularly publishes fungicide resistance management recommendations for growers (<https://afren.com.au/resources/#management-guide>). Similarly, Wine Australia and SAAFE^{CRC} have established a community of researchers to monitor and manage fungicide resistance in Australian grapevines (<https://www.crcsaafe.com.au/research/projects/fungicide-resistance-in-grapevine>). This collaboration has resulted in the publication detailing the status of fungicide resistance in grapevines in Australia (Ismail *et al.*, 2025). Unfortunately, no similar network for fungal, bacterial, viral, or nematode plant pathogens exists in the vegetable industry, leaving the industry vulnerable. Pathogens of Australian levy vegetables considered to pose a high or medium risk of developing resistance to fungicides are grey molds of several crops, cucurbit downy mildew, cucurbit powdery mildews, white rust of brassicas, Ascochyta blight and blight or purple spot of peas, downy mildew of lettuce, and powdery mildew of carrots. In 2024-25 production of these crops was valued at AUD \$2.17 billion, accounting for 36% of the total value of all fresh vegetable production for that year. The occurrence of resistance in any of these crops could cause significant economic damage to individual growers and to industry. The findings of this review argue for the establishment of an appropriate network of adequately resourced individuals to proactively monitor for bacterial and fungicide resistance in the high and medium combined fungicide × pathogen risk category and to recommend strategies aimed at reducing the risk of resistance arising.

Outputs/Communications

1. Appendix 1A: A review of evidence for antimicrobial resistance in Australian levy vegetable crops.
2. Appendix 1B: VegeNotes #1 (submitted to AusVEG in March for publication in the Spring 2026 edition of the magazine): Staying Ahead of Antimicrobial Resistance (AMR): Protecting Australian Levy Vegetable Crops and Markets. Link to publication: [Staying ahead of antimicrobial resistance \(AMR\): Protecting Australian levy vegetable crops and markets - AUSVEG](#)

Deliverable 2

Introduction

Australian vegetable supply chains are characterised by diverse production systems, complex farm-to-fork pathways, and comprehensive food safety and quality assurance frameworks that influence both the occurrence and management of antimicrobial-resistant microorganisms. Deliverable 2 was undertaken to establish the scientific, regulatory, economic, and industry evidence base required to support a SLRA of AMR in Australian vegetable production. Collectively, these deliverables integrate current scientific knowledge, industry practices, data governance systems, economic analyses, grower perspectives, and extension activities to provide a comprehensive understanding of AMR risks and identify opportunities for improved surveillance, stewardship, and risk management across the vegetable supply chain.

Rationale

Effective management of AMR requires an integrated understanding of the biological, economic, regulatory, and operational factors that influence its emergence and dissemination throughout vegetable production systems. Existing information relating to AMR in horticulture is fragmented across scientific literature, industry knowledge, regulatory frameworks, and supply chain practices, limiting evidence-based decision-making. Deliverable 2 was therefore designed to consolidate these diverse information sources into a coherent evidence base that supports the development of a SLRA for Australian levy vegetables. The work examined scientific evidence for AMR and chemical co-selection, evaluated food safety and data governance systems, quantified the economic importance of priority vegetable commodities, investigated potential contamination pathways within production systems, and translated project findings into practical guidance for industry stakeholders. Together, these complementary activities identify critical knowledge gaps, inform future surveillance priorities, strengthen antimicrobial stewardship, and provide the scientific and practical foundation required to protect food safety, maintain market access, and enhance the long-term resilience and sustainability of Australian vegetable production systems.

Deliverable 2.1 and 2.7: Literature Review, Evidence Synthesis and Knowledge Translation

A scientific evidence base was established to underpin the project by undertaking a comprehensive scoping review of AMR and chemical-resistant pathogens in fresh produce systems. The review followed the PRISMA-ScR framework to systematically map the breadth of available evidence, rather than estimate a single prevalence or intervention effect. This approach was selected because AMR in horticulture is an emerging and multidisciplinary field encompassing microbiology, plant pathology, food safety, environmental science, regulatory policy, and quantitative risk assessment. The review was designed to identify knowledge gaps, inform the development of the project's SLRA (Deliverable 3), and support future industry guidance.

A comprehensive search of peer-reviewed and grey literature published between 2000 and 2025 was undertaken using PubMed, Scopus, Web of Science, and major institutional sources, including Food and Agriculture Organization (FAO), World Health Organization (WHO), Codex Alimentarius, Food Standards Australia and New Zealand (FSANZ), U.S. Food and Drug Administration (FDA), and European Union regulatory frameworks. Following systematic screening and duplicate removal, 216 unique publications were assessed and synthesized into four analytical domains:

- i. AMR and pathogen prevalence in fresh produce systems;
- ii. mechanisms of AMR and chemical co-selection;
- iii. regulatory and voluntary management frameworks; and
- iv. risk assessment methodologies relevant to vegetable production.

AI-assisted evidence synthesis software (ElicitPRO) was used to improve the efficiency of literature screening and data extraction, with all findings independently verified by the project team. The review demonstrated that antimicrobial-resistant microorganisms and antimicrobial resistance genes (ARGs) have been detected throughout vegetable production systems, including irrigation water, soils, manures, composts, fresh produce, processing environments, and retail products. Leafy vegetables, particularly lettuce and spinach, represented the largest body of evidence, while studies involving carrots,

cucumbers, herbs, and mixed salads were comparatively limited. The evidence consistently identified irrigation water, organic amendments, soil contact, harvesting, washing, processing, and retail handling as important contamination pathways. Fresh-cut and ready-to-eat vegetables generally exhibited higher bacterial loads and AMR prevalence than whole produce, highlighting the importance of post-harvest handling in influencing contamination risks.

These findings supported the project's farm-to-fork approach, recognizing that AMR risk is shaped by both pre-harvest and post-harvest practices. The review also highlighted the complex biological mechanisms responsible for the emergence, persistence, and dissemination of AMR within horticultural systems. Horizontal gene transfer, mediated through plasmids, integrons, insertion sequences, and other mobile genetic elements, was identified as a key mechanism facilitating the movement of ARGs between environmental microorganisms and potential human and plant pathogens. Importantly, the review showed that resistance selection is not driven solely by antibiotic exposure. Agricultural fungicides, herbicides, heavy metals, and disinfectants can all contribute to chemical co-selection by creating environmental conditions that favor resistant microorganisms or enhance the transfer of ARGs. These findings demonstrated that agrochemical stewardship should be considered an integral component of AMR risk management alongside conventional food safety measures.

Evaluation of current regulatory and voluntary assurance frameworks revealed that existing food safety systems remain largely focused on conventional microbial indicators, chemical residues, and general hygiene practices. Although Australian and international standards provide comprehensive guidance for water quality, food safety, and agricultural production, they rarely include AMR-specific monitoring or surveillance. Existing testing programs therefore provide limited information on antimicrobial-resistant organisms, ARGs, mobile genetic elements, or chemical co-selection processes. The review concluded that future assurance systems will require more targeted AMR surveillance integrated within existing food safety frameworks rather than replacing current certification systems. Assessment of published risk assessment methodologies demonstrated that most quantitative microbial risk assessments have focused on human foodborne pathogens and only rarely consider AMR-specific hazards. No published studies were identified that developed a comprehensive quantitative risk assessment framework for AMR affecting both human health and crop protection within vegetable production systems. Current evidence was therefore considered more appropriate for relative risk ranking and scenario comparison than for estimating absolute probabilities of harm. This finding directly informed the project's decision to develop a screening-level, Monte Carlo-based relative risk assessment that could incorporate uncertainty while identifying critical control points and research priorities. Integration of evidence across all four domains demonstrated that AMR in vegetable production should be viewed as a systems-level issue involving multiple interconnected reservoirs rather than a single contamination event. The review consistently identified upstream production inputs including seed and nursery material, irrigation water, soil, composts, organic amendments, and crop protection practices as the dominant determinants of AMR risk. Downstream activities such as harvesting, washing, processing, storage, transport, and retail handling primarily influence the persistence and redistribution of resistant microorganisms rather than their initial establishment. These findings provided the scientific justification for the structure of Deliverable 3, including the selection of ESBL-producing *E. coli* as the human health indicator organism and the incorporation of agrochemical resistance pathways for plant health risk assessment.

The principal output of Deliverable 2.1, 2.6 and 2.7 was the peer-reviewed review manuscript, ***Risk Assessment Frameworks for Antimicrobial Resistance and Chemical Co-selection in Ready-to-Eat Vegetables: A Critical Review, prepared by Jowenna X. F. Sim, Claire Hayward, Mark Drew, Fran Lopez-Ruiz, Sukhvinder Pal Singh, Nicholas J. Ashbolt, and Barbara Drigo.*** Supporting outputs included comprehensive supplementary evidence tables, a farm-to-fork conceptual framework illustrating AMR introduction and dissemination throughout vegetable supply chains, and a VegNote extension publication translating the scientific findings into practical guidance for vegetable growers and industry stakeholders. Together, these outputs provide a robust scientific foundation for future research, surveillance, policy development, and industry extension while supporting evidence-based decision-making for antimicrobial resistance management across Australian vegetable production systems.

Deliverable 2.2: Review of Data Systems and Data Governance Standards Across the Australian Vegetable Production Supply Chain

Major data governance systems and quality assurance frameworks operating across the Australian vegetable industry were reviewed to evaluate their capacity to support food safety, traceability, regulatory compliance, and future AMR risk management. The review examined mandatory regulatory requirements alongside the principal industry certification schemes, highlighting how effective data governance underpins modern vegetable production by ensuring that information is accurate, secure, traceable, auditable, and available to support decision-making and market access. Australian vegetable producers operate within a complex regulatory environment that often requires compliance with multiple overlapping

certification programs. The legislative foundation is provided by the FSANZ Food Standards Code, which establishes mandatory food safety requirements based on Hazard Analysis and Critical Control Point (HACCP) principles. The Code requires businesses to implement documented food safety programs, maintain traceability, manage production inputs, monitor water quality, ensure personnel competency, and maintain comprehensive records that support verification and regulatory audits. The recently introduced Primary Production and Processing Standard for Leafy Vegetables further strengthens these requirements through specific provisions relating to production inputs, harvesting, processing, sanitation, and traceability.

Beyond legislative requirements, growers commonly participate in internationally recognised quality assurance programs including Freshcare, BRCGS, GLOBALG.A.P., SQF, and the Harmonised Australian Retailer Produce Scheme (HARPS). Although differing in scope, these certification systems share common requirements for documented management systems, risk assessments, staff training, internal audits, external certification, corrective actions, supplier management, product traceability, and continual improvement. Together, they provide robust governance systems that support food safety, product quality, and customer confidence across domestic and export markets. Freshcare provides an Australian-specific certification framework covering food safety, product quality, and environmental management. Certification requires detailed documentation of production practices, chemical use, irrigation water, fertilisers, soil amendments, harvesting, packing, traceability, product recall procedures, and environmental stewardship. Similarly, BRCGS, GLOBALG.A.P., and SQF require comprehensive documentation of HACCP plans, supplier approval, sanitation, infrastructure, environmental monitoring, product testing, equipment maintenance, corrective actions, and management review. Annual audits and ongoing verification ensure continual improvement and consistent implementation of documented procedures. HARPS complements these systems by harmonising retailer-specific food safety requirements into a single audit process, reducing duplication while strengthening traceability, product testing, supplier management, microbiological monitoring, and product recall capability.

Ethical and social compliance programs, including Fair Farms and Sedex, extend governance beyond food safety by addressing employment practices, workplace health and safety, labour standards, environmental performance, and business ethics through similarly rigorous documentation and audit processes. The review identified several common elements across all certification systems, including comprehensive record keeping, document control, staff competency and training, internal verification, external auditing, traceability, corrective action processes, and continuous improvement. These shared governance principles provide highly structured information systems capable of identifying hazards, demonstrating compliance, supporting product recalls, and maintaining consumer confidence. Although existing certification schemes were not specifically developed to address AMR, they provide a strong foundation for incorporating AMR surveillance into existing food safety programs. Records relating to irrigation water, composts, biosolids, agrochemical use, sanitation, environmental monitoring, and product testing could readily be expanded to include AMR monitoring and stewardship activities. The review concludes that Australia's established data governance and quality assurance systems provide an effective platform for integrating future AMR risk assessment, surveillance, and management strategies while avoiding the need to develop entirely new regulatory frameworks.

Deliverable 2.3: Economic and Trade Data for Selected Levy Vegetables

The economic importance, production trends, domestic market distribution, and export performance of three vegetable categories identified as priorities for AMR risk assessment: bagged leafy salad vegetables, carrots, and cucumbers were investigated. These commodities were selected because they are frequently consumed raw or with minimal processing, increasing the potential for exposure to antimicrobial-resistant microorganisms. This analysis provides the economic context required to prioritise AMR surveillance and risk management by identifying commodities with high production value, significant domestic consumption, and important export markets.

The Australian vegetable industry remains a major contributor to the national economy, producing 3.78 million tonnes of levy vegetables with a farm-gate value of AUD \$6.03 billion during 2024–25. Approximately 59% of production was supplied to the domestic fresh market, 36% was processed, and 5% exported as fresh produce. Fresh vegetables destined for domestic consumption were distributed primarily through retail outlets (81%), with the remaining 19% supplied to the food service sector. Despite relatively stable production volumes over recent years, the wholesale value of vegetables supplied to retail markets has continued to increase, reflecting sustained consumer demand and improved market returns. The selected commodities—bagged leafy salad vegetables, carrots, and cucumbers—collectively represented approximately 758,500 tonnes of production during 2024–25, equivalent to 20% of Australia's total levy vegetable production volume. More importantly, these crops generated approximately AUD \$1.60 billion in farm-gate value, accounting for 26.5% of the total value of the Australian vegetable industry. Their substantial economic contribution highlights the importance of

protecting these supply chains from emerging risks, including AMR.

Bagged leafy salad vegetables represented the largest economic component of the selected commodities, with an estimated production value exceeding AUD \$1.12 billion in 2024–25. Because official statistics do not report bagged salads as a separate commodity, the analysis used a proxy comprising cabbage, spinach, silverbeet, kale, leafy Asian vegetables, leafy salad vegetables, and head lettuce. Leafy salad vegetables alone accounted for more than 60% of the value of this category, followed by head lettuce. Domestic consumption dominates this market, with relatively small export volumes. Approximately 70% of wholesale value was supplied through retail channels and 30% through food service. Production is concentrated primarily in Victoria, Queensland, and New South Wales.

Carrots generated a farm-gate value of approximately AUD \$253 million from just over 304,000 tonnes of production. Unlike leafy vegetables, carrots represent an important export commodity, with almost 29% of production exported and export earnings exceeding AUD \$74 million in 2024–25. Western Australia dominates national carrot production and accounts for over 90% of export volume. Major export destinations include the United Arab Emirates, Saudi Arabia, Malaysia, Singapore, and Qatar, demonstrating the significance of carrots within Australia's fresh vegetable export industry. The domestic market remains strong, with retail sales accounting for approximately 79% of fresh supply. Cucumbers contributed approximately AUD \$225 million to farm-gate production value from almost 114,000 tonnes of production. Production has increased steadily over recent years, although exports remain negligible, representing less than 0.1% of total production. The industry is therefore heavily dependent on domestic consumption, with approximately 86% of fresh supply distributed through retail markets and the remainder through food service. Production is concentrated in South Australia and Queensland, while Victoria contributes the largest proportion of the small export trade.

Overall, this analysis demonstrates that bagged leafy salad vegetables, carrots, and cucumbers represent economically important components of Australian vegetable production, collectively contributing more than one-quarter of the industry's total farm-gate value. Their differing market characteristics—including high domestic consumption for leafy vegetables and cucumbers, and strong export dependence for carrots—highlight the need for commodity-specific approaches to AMR risk management. The economic and trade data presented provide an important foundation for prioritising surveillance activities, evaluating potential economic consequences of antimicrobial resistance, and informing future industry investment in stewardship, biosecurity, and risk mitigation strategies aimed at protecting both domestic and export markets.

Deliverable 2.4: Scoping Study of AMR Risks in Australian Vegetable Production

A scoping study that investigated potential pathways for the introduction, persistence, and spread of AMR within Australian production systems for leafy greens, carrots, and cucumbers was conducted. The findings are based on a limited sample of growers across major vegetable-producing regions in eastern Australia and provide an initial evidence base to guide future research and surveillance. The study identified several potential entry points for AMR into vegetable production systems. These included seeds and seedlings, composts and organic soil amendments, cocopeat growing media used in protected cropping, irrigation water, and post-harvest packing and processing facilities. The review found that limited information is available regarding fungicide and bactericide treatments applied during seed and seedling production, reducing growers' ability to implement effective resistance management strategies. Composts, biosolids, manures, and imported cocopeat substrates were also identified as potential pathways requiring further investigation because their contribution to the introduction and persistence of resistant microorganisms under Australian conditions remains uncertain. The study demonstrated that vegetable production systems operate under a range of environmental conditions and increasingly complex supply chains. Large processing and packing operations often consolidate produce from multiple growers and supply products under numerous retail brands. Recent national food recalls involving leafy vegetables highlighted how contamination occurring during harvesting, washing, processing, or packing can be amplified across multiple products and markets. Although these incidents were not specifically linked to AMR, they illustrate how contamination pathways could facilitate the dissemination of antimicrobial-resistant microorganisms if present. Grower responses indicated a high level of awareness and compliance with existing food safety, quality assurance, integrated pest management, and pesticide resistance management programs, including Freshcare, GlobalG.A.P., HARPS, SQF, and other HACCP-based certification systems. These schemes provide important safeguards for reducing biological, chemical, and physical hazards throughout production and offer a strong foundation for integrating future AMR stewardship initiatives. However, discussions with growers also indicated that AMR is not yet considered a high-priority issue, despite recognition that the detection of AMR in vegetable supply chains could have significant economic, trade, and reputational consequences.

Deliverable 2.5: Dissemination of Information on Antimicrobial Resistance (AMR) and Chemical-Resistant Pathogens

Communication of project outcomes and increasing industry awareness of AMR and chemical-resistant plant pathogens was done through targeted extension and stakeholder engagement activities. The project committed to disseminating information through the national VegNET network and industry events, with the aim of improving grower understanding of AMR risks and promoting evidence-based management practices within Australian vegetable production systems. During the reporting period, extension activities were led by Dr Mark Drew and included participation in the VicVID Field Days in Tyabb, Victoria (7–8 May 2026), attendance at the associated Elders Networking Event, and delivery of a grower information evening in Woolgoolga, NSW (20 May 2026). These activities provided opportunities to engage directly with vegetable growers, agricultural advisers, crop protection companies, seed suppliers, and other industry stakeholders. Although formal speaking opportunities at the VicVID Field Days had been allocated before project participation was confirmed, the event nevertheless provided valuable opportunities for informal engagement.

Dr Drew held discussions with growers, seed companies, agrochemical suppliers, and technical specialists regarding antimicrobial resistance, fungicide resistance, and disease management in vegetable production systems. These conversations also provided valuable insight into current industry knowledge, perceptions, and emerging production challenges, while strengthening relationships with key industry stakeholders. The Woolgoolga grower information evening provided the principal extension activity for the project. Delivered in collaboration with AgNova Technologies Pty Ltd and Ace Ohlsson Woolgoolga, the event was attended by 27 protected-cropping cucumber growers, several of whom also produced berry crops. Dr Drew presented an overview of the risks associated with AMR in vegetable production, summarised key findings from the national grower survey, and discussed future research priorities for reducing AMR risks in ready-to-eat vegetable supply chains. The presentation was complemented by an industry session on fungicide stewardship, creating an integrated discussion on resistance management and responsible crop protection practices. Informal networking following the presentations provided additional opportunities for knowledge exchange and discussion of practical management issues.

A key finding from these extension activities was that AMR is not currently considered a major concern by most vegetable growers. Instead, growers remain primarily focused on production efficiency, profitability, input costs, and day-to-day business management. In contrast, awareness of fungicide resistance and established resistance management strategies was consistently high, reflecting decades of successful industry stewardship and extension programs delivered by the crop protection sector. These observations highlighted an important opportunity for future extension activities. Existing grower knowledge of fungicide resistance provides a strong foundation upon which AMR awareness and stewardship messages can be built. Future communication should therefore integrate AMR within existing resistance management and crop protection programs, demonstrating the links between food safety, plant health, and sustainable production. This approach is expected to improve industry understanding of AMR while supporting the adoption of science-based management practices that strengthen food safety, biosecurity, and long-term resilience across Australian vegetable supply chains.

Results Summary

Based on the findings of Deliverables 2, the following recommendations are proposed to strengthen AMR surveillance, risk management, and stewardship within the Australian vegetable industry.

1. **Establish a coordinated national AMR surveillance program for vegetable production.** Surveillance should focus on priority commodities, including ready-to-eat leafy vegetables, carrots, and cucumbers, and monitor antimicrobial-resistant microorganisms, antimicrobial resistance genes, mobile genetic elements, and resistance to fungicides and bactericides across the production chain.
2. **Integrate AMR monitoring into existing food safety and quality assurance systems.** Rather than developing new certification programs, existing frameworks such as Freshcare, HARPS, GLOBALG.A.P., SQF, and BRCGS should be enhanced to include AMR surveillance, antimicrobial stewardship, and monitoring of high-risk production inputs such as irrigation water, composts, organic amendments, and post-harvest environments.
3. **Develop a national research and monitoring network for horticultural AMR.** Similar to successful initiatives in the grains and wine industries, a collaborative network involving researchers, government agencies, industry, diagnostic laboratories, and crop protection companies should be established to coordinate surveillance, data

sharing, research, and extension activities.

4. **Prioritise research on critical knowledge gaps.** Future research should investigate the prevalence and persistence of AMR in Australian vegetable production systems, the role of irrigation water and organic amendments, chemical co-selection associated with agrochemical use, and the contribution of post-harvest processing to the dissemination of resistant microorganisms.
5. **Strengthen antimicrobial and agrochemical stewardship.** Resistance management should extend beyond antibiotics to include responsible use of fungicides, bactericides, disinfectants, herbicides, and other agricultural chemicals that may contribute to resistance selection. Stewardship programs should promote integrated pest and disease management practices that minimise selection pressure while maintaining crop productivity.
6. **Improve data collection and governance for AMR.** Existing traceability and record management systems provide an excellent platform for incorporating AMR-related information. Standardised protocols for data collection, storage, reporting, and sharing should be developed to support evidence-based decision-making and facilitate future quantitative risk assessments.
7. **Expand quantitative risk assessment capability.** The SLRA developed through this project should be refined using Australian surveillance data to support more robust quantitative assessments of both human health and plant health risks associated with AMR.
8. **Increase industry awareness through targeted extension programs.** Extension activities should build on growers' existing understanding of fungicide resistance by integrating AMR messages within established crop protection and food safety programs. Practical guidance should emphasise risk reduction, stewardship, and the shared benefits of protecting productivity, food safety, and market access.
9. **Support policy development through a One Health approach.** Future policies addressing AMR in horticulture should recognise the interconnected nature of human, animal, plant, and environmental health and promote coordinated action across government, research organisations, industry, and supply chain stakeholders.
10. **Maintain investment in collaborative research and innovation.** Continued investment by Hort Innovation, SAAFC^{CRC}, industry partners, and government agencies is essential to generate the scientific evidence, surveillance capacity, and extension programs required to proactively manage antimicrobial resistance and safeguard the long-term sustainability, competitiveness, and resilience of the Australian vegetable industry.

Outputs/Communications

The project generated the following key deliverables and extension outputs:

- Appendix 2A: Deliverable 2.1, 2.6 and 2.7: *Risk Assessment Frameworks for Antimicrobial Resistance and Chemical Co-selection in Ready-to-Eat Vegetables: A Critical Review*
- Appendix 2B: Deliverable 2.2: *Review of Data Systems and Data Governance Standards Across the Australian Vegetable Production Supply Chain*
- Appendix 2C: Deliverable 2.3: *Economic and Trade Data for Selected Levy Vegetables (Bagged Leafy Salad Vegetables, Carrots and Cucumbers)*
- Appendix 2D: Deliverable 2.4: *Exploring the Potential for Antimicrobial Resistance in Ready-to-Eat Vegetables: A Farmer-Level Scoping Study*
- Appendix 2E: Deliverable 2.5: *Grower Engagement and Knowledge Dissemination Activities*
- Appendix 2F: VegeNotes #2 (submitted to AusVEG in March for publication in the Spring 2026 follow-up edition of the magazine): *Antimicrobial Resistance in Ready-to-Eat Vegetables: What We Know, What We Don't, and What We Can Do. Publisher AUSVEG, December 2026.*

- Appendix 2G: VegeNotes #3 (submitted to AusVEG in March for publication; however, the decision was made not to publish this VegeNote). *Economic and Trade Analysis of Selected Levy Vegetable Crops: Bagged Leafy Salads, Carrots, and Cucumbers*. Contacts: Jessica Muller (AusVEG) and Rosalie Daniel (AusVEG).

Deliverable 3

Summary

This deliverable reports the findings of a modular SLRA examining AMR risks across the Australian horticultural supply chains for three levy crops: leafy greens, cucumbers, and carrots. Two parallel risk pathways were assessed for each crop: (1) human health risk from extended-spectrum beta-lactamase (ESBL)-producing *E. coli* on fresh produce; and (2) plant health risk from reduced agrochemical efficacy due to resistance in target plant pathogens. The assessment identified the key pathogens and resistance mechanisms at each supply chain stage, mapped points of pathogen introduction and amplification, and used Monte Carlo simulation to produce risk pathway rankings and directional risk characterisations for each scenario. Semi-quantitative results, sensitivity figures, and detailed methodology are provided in Appendix 3A, Appendix 3B and Appendix 3C. The most consistent finding across all six models is that pre-production inputs—seed, nursery material, irrigation water quality, and soil inoculum burden—are the primary determinants of AMR outcomes for both risk pathways. This has direct implications for where grower and industry management effort is best directed.

Introduction

AMR in horticulture manifests across two dimensions: the carriage of clinically relevant resistant pathogens on fresh produce, and the progressive enrichment of resistance in plant pathogen populations under agrochemical selection pressure. This SLRA addresses both simultaneously for the first time across three Australian levy crops, providing an evidence base for risk prioritization and management investment. A screening-level approach was selected because: validated dose-response relationships are not available for ESBL-producing *E. coli* as a clinical outcome; plant pathogen efficacy thresholds are not established for the specific crop-chemical combinations assessed; and the primary decision need—where risk management effort should be directed—is better served by a credible risk ranking than by precise probability estimates of harm at this stage. Results are semi-quantitative where possible, directional and should be interpreted accordingly. It should be read in conjunction with Deliverable 1 and Deliverable 2, which provide the practitioner context and evidence base that underpin the model parameterization.

Methodology

Six Monte Carlo simulation models were developed (one *E. coli*/human health model and one plant health/resistance model for each of the three crops). Each model was structured as a sequential supply chain, with risk accumulating or being modified at each stage from pre-production inputs through to consumer exposure (human health) or next-season inoculum (plant health). Where possible, parameters were assigned probability distributions from: a systematic literature review (reported in Deliverable 2); Australian grower-practice surveys (Deliverable 1 & Deliverable 2); and estimates where empirical data were insufficient. Results are reported as median (central estimate under typical conditions) and 90th percentile (P90; value exceeded in approximately one in ten scenarios). Sensitivity analysis used Spearman rank correlation to rank risk pathways (High: mean $|p| > 0.10$; Moderate: $0.05-0.10$; Low: < 0.05). The SLRA rationale, parameter distributions, calculated variable formulas, and sensitivity analysis outputs are provided in Appendix.

Results and discussion

Human health pathway: ESBL-producing *E. coli*

Total *E. coli* concentration and ESBL-resistant fraction at the point of consumption are reported for each crop. Concentration is evaluated against FSANZ microbiological reference criteria for ready-to-eat vegetables (FSANZ, 2025). ESBL-resistant fraction is evaluated against a precautionary benchmark of 20–30%, derived from international QMRA literature (EFSA, 2021; Overdevest et al., 2011; Mughini-Gras et al., 2019) in the absence of an Australian regulatory limit for ESBL fraction on fresh produce.

Table 1. Summary of human health SLRA results for the three levy crops. Total E. coli concentration evaluated against FSANZ microbiological reference criteria for ready-to-eat vegetables: Satisfactory <100 CFU/g (green); Borderline 100–1,000 CFU/g (orange);

Unsatisfactory >1,000 CFU/g (red) (FSANZ, 2025). ESBL fraction benchmark of 20–30% is indicative, derived from international QMRA literature.

Crop	<i>E. coli</i> conc. at consumption (CFU/g)		ESBL fraction at consumption	
	Median	P90	Median	P90
Leafy greens	3×10^{-3}	2.7×10^3	36.4%	63.0%
Cucumbers	3.3×10^3	1.9×10^5	20.1%	46.0%
Carrots	1	2.2×10^4	6.6%	21.9%

Across all three crops, the ESBL-resistant fraction at consumption was driven almost entirely by the pre-production resistance fraction (Spearman correlations of $\rho = 0.72$ (leafy greens, via nursery material), $\rho = 0.96$ (cucumbers), and $\rho = 0.98$ (carrots). This means that the resistance characteristics of *E. coli* entering the system via seed, nursery, and early irrigation events determine what reaches the consumer, largely independently of production and post-harvest practices. ESBL fraction and total *E. coli* concentration are independent risk dimensions with different drivers. Concentration is primarily determined by field temperature and time, while ESBL fraction is determined by pre-production inputs. Interventions targeting one dimension may not reduce the other.

The cucumber scenario is notable in that post-farm-gate practices have greater leverage over human exposure than for the other two crops. Cold storage at retail was the dominant risk pathway for cucumbers (mean $|\rho| = 0.23$, High importance), reflecting the common practice of ambient cucumber retail storage in Australia (Figure 19.). Ensuring cucumbers are refrigerated at retail would meaningfully reduce post-harvest *E. coli* growth on contaminated products, an achievable intervention that does not require changes to on-farm practice.

Carrots present the most favourable human health profile, attributable to the direct-sown growing system which eliminates the nursery contamination pathway in the current assessment. However, the carrot scenario showed extreme sensitivity to field temperature. Moving T_{field} from median to P90 produced a significant increase in estimated dose per serving in one-at-a-time sensitivity analysis (Table 1). Warm-season carrot production is therefore a qualitatively different risk scenario from cool-season production, and rapid post-harvest cooling is the single highest-impact intervention for this crop.

Plant health pathway: agrochemical resistance

Pre-treatment and post-treatment resistance fractions are reported for each crop-chemical combination. The resistance fraction estimates are presented within a risk characterisation framework adapted from the resistance frequency x population response nomenclature established for the Australian grains sector (Table 2) (GRDC, 2023). This framework provides a structured, externally anchored characterisation without requiring field-trial-derived efficacy thresholds, which are not currently available for the specific crop-pathogen combinations assessed in an Australian horticultural context.

An important consideration across all three scenarios is that pathogen presence does not directly equate to disease expression. A lag period typically exists between pathogen establishment and visible symptom expression, the duration of which varies by pathogen and environmental conditions. This lag period may represent a window for targeted intervention. The SLRA does not characterize disease severity or economic injury; product affected by disease may be redirected to alternative commercial lines rather than resulting in total loss, and outcomes depend on market specifications and processing options available to the grower. Future extensions could draw on established economic dose-optimisation approaches developed for other cropping systems (e.g. van den Bosch et al., 2018) to quantify these thresholds explicitly.

Table 2 Risk characterisation framework for plant pathogen resistance, adapted from GRDC (2023) fungicide resistance nomenclature for Australian grain crops. Frequency bands: Low <10–15%; Medium 10–30%; High >30% of the field pathogen population. Highlighted cells indicate the characterization for each scenario assessed (see Table 3).

Resistance frequency in field population	Population response to fungicide treatment			
	Sensitive	Lab detection	Reduced sensitivity	Resistance
Zero	Unlikely	Unlikely	Unlikely	Unlikely
Low	Unlikely	Unlikely	Unlikely	Likely
Medium	Unlikely	Unlikely	Possible	Almost certain
High	Unlikely	Unlikely	Likely	Certain

Table 3 Plant health SLRA results placed within the risk characterisation framework (Table 2). Resistance mechanisms are therefore a critical modifier of the population response.

Scenario	Pre-treatment resistance		Frequency band	Post-treatment resistance (median)	Risk characterisation
	Median	P90			
Leafy greens/copper (bacterial phyllosphere)	28.2%	70.2%	Medium	99.1%	Almost certain
Cucumbers/strobilurin (<i>P. cubensis</i>)	14.7%	30.5%	Low–Medium	~100%	Likely
Carrots phenylamide (<i>Pythium/Phytophthora</i>)	18.6%	35.0%	Medium	95.6%	Almost certain

The “Certain”, “Almost certain”, and “Likely” characterisations in Table 3 describe the probability that the field pathogen population has reached the ‘Resistance’ population-response category defined in Table 2, that is, the likelihood that treatment will fail to control the population at existing chemical rates. They are not a statement about crop failure or yield loss: pathogen presence and even population-level resistance do not directly translate to disease expression or economic damage, and the model does not characterize disease severity or economic injury.

Across all three plant health scenarios, the resistance fraction in the inoculum entering the following season closely mirrors the post-treatment resistance fraction, reflecting the persistence of resistant organisms in the soil and crop environment. This result assumes continuous cultivation of the same host crop without an intervening non-host rotation break; the model does not explicitly capture the inoculum-dilution effect that a rotation break can provide for the host-specific pathogens. Without deliberate intervention to reduce the soil resistance burden, conditions at the start of each crop cycle will be similar to, or more resistance-enriched than the previous season. The soil resistance fraction (Frac_res_soil) was the dominant driver across all three scenarios, confirming that cumulative chemical use history in each field is the primary determinant of starting conditions each season.

Resistance enrichment will occur at any resistance fraction, even below the frequency band boundaries used for risk characterisation above, because resistant individuals survive chemical treatment while susceptible individuals are selectively eliminated. The frequency × consequence framework (Table 2) does not imply that below a given frequency there is no risk, but that the magnitude and speed of enrichment, and the immediate impact on control, differ across the frequency range.

The absence of validated efficacy thresholds for these crop-chemical combinations in Australian conditions is itself a significant finding of this assessment. This is a recognised challenge within the plant pathology and resistance management research community, reflecting the cost and logistical demands of the field trial work required to establish such thresholds. The model framework developed here is designed to be updated as Australian-specific threshold data become available. Future iterations incorporating spatiotemporal factors (landscape position, surrounding land use, local climate variability, and seasonal conditions) are expected to further refine the risk characterisation and provide growers with more location-specific guidance.

Risk pathway rankings: Cross-crop summary

The dominant risk pathways identified by sensitivity analysis are consistent across crops and risk dimensions. Pre-production inputs (seed, nursery, soil, and irrigation water) ranked as the highest-importance pathways across all six models. Chemical treatment parameters ranked Low importance across all three plant health models, confirming that by the time treatment is applied, the resistance trajectory has largely been determined by upstream conditions.

Table 4 Dominant risk pathways for each crop across both risk dimensions. Full pathway rankings by supply chain module are provided in Appendix 3B and Appendix 3C.

Crop	Human health — top pathway	Plant health — top pathway
Leafy greens	Harvesting (blade transfer; High, $\rho=0.45$)	Irrigation water quality (High, mean $ \rho =0.144$)
Cucumbers	Cold storage at retail (High, mean $ \rho =0.228$)	Soil amendment/soil resistance fraction (High, mean $ \rho =0.130$)

Carrots	Field temperature/growing time (High, mean p =0.107)	Soil amendment/soil resistance fraction (High, mean p =0.113)
---------	---	--

Outputs

Output summary

Output	Description	Detail
Deliverable 1		
Appendix 1A	A review of evidence for antimicrobial resistance in Australian levy vegetable crops.	Article summarizing the activities, key findings, and outcomes of Deliverable 1 , providing a comprehensive overview of the review of antimicrobial resistance and fungicide/bactericide resistance in Australian levy vegetable crops, together with its implications for industry, future surveillance, and resistance management.
Appendix 1B	VegeNotes #1 Staying Ahead of Antimicrobial Resistance (AMR): Protecting Australian Levy Vegetable Crops and Markets.	A communication article highlighting the key findings and outcomes of Deliverable 1 was prepared to support knowledge translation and industry engagement. The article was submitted to AUSVEG in March 2026 for publication in the Spring 2026 edition of VegeNotes, with the aim of communicating the project's findings and their practical implications for Australian vegetable growers and industry stakeholders. AUSVEG contacts: Jessica Muller and Rosalie Daniel.
Deliverable 2		
Appendix 2A	Risk Assessment Frameworks for Antimicrobial Resistance and Chemical Co-selection in Ready-to-Eat Vegetables: A Critical Review	Deliverable 2.1 and 2.7 Conduct a literature review of existing risk assessment methodologies for AMR and chemical-resistant pathogens in levy vegetables.
Appendix 2B	Review of Data Systems and Data Governance Standards Across the Australian Vegetable Production Supply Chain	Deliverable 2.2 A review of data systems and data governance standards across supply chain through discussions with stakeholders conducted through online activities and meetings.
Appendix 2C	Economic and Trade Data for Selected Levy Vegetables (Bagged Leafy Salad Vegetables, Carrots and Cucumbers)	Deliverable 2.3 Collect and compile relevant economic and trade data for the selected levy vegetables.
Appendix 2D	Exploring the Potential for Antimicrobial Resistance in Ready-to-	Deliverable 2.4 Conduct meetings to gather industry and consumer perspectives and estimates of the economic impact of AMR on the industry.

	Eat Vegetables: A Farmer-Level Scoping Study	
Appendix 2E	<i>Grower Engagement and Knowledge Dissemination Activities</i>	Deliverable 2.5 To effectively disseminate information on AMR and chemical-resistant pathogen issues to growers, we organized a series of meetings utilizing the national extension network, VegNET. and at the Hort Connections Conference in June 2026.
Appendix 2F	VegeNotes #2 (submitted to AusVEG in March for publication in the Spring 2026 follow-up edition of the magazine): <i>Antimicrobial Resistance in Ready-to-Eat Vegetables: What We Know, What We Don't, and What We Can Do.</i> Contacts: Jessica Muller (AusVEG) and Rosalie Daniel (AusVEG).	Deliverable 2.6 Industry facing factsheet suitable for publication by the Vegetable industry communications program (VG22000) and the VEGNET 3.0 program (VG21000) which summarizes project findings and recommendations, including perceived benefits of adding additional pre- and post-harvest AMR and chemical-resistant pathogens management activities to existing practices.
Deliverable 3		
Appendix 3A	Risk Assessment Framework and Model Development	Documents on the SLRA methodology: risk profile and problem formulation, hazard identification and characterisation for both pathways, conceptual models, model structure and mathematical implementation for the human health and plant health models, exposure assessment, risk characterization (reference thresholds), key assumptions, variability/uncertainty, and model validation and future iterations.
Appendix 3B	Quantitative Results: Plant Health (Agrochemical Resistance)	Three figures per model: (A) parameter sensitivity heatmap, (B) overall pathway ranking, (C) segmented module ranking
Appendix 3C	Quantitative Results: Human Health (<i>E. coli</i> / ESBL)	Three figures per model: (A) parameter sensitivity heatmap, (B) overall pathway ranking, (C) segmented module ranking
Appendix 3D	Behaviors and Practices Associated with AMR Risk	Grower practices identified as contributing to AMR risk, organised by chemical management, irrigation and water management, soil and input management, and post-harvest and consumer practices.
Appendix 3E	Industry Stewardship Programs	Existing industry stewardship programs and frameworks relevant to resistance management: FRAC guidelines, FreshCare and food safety certifications, and Integrated Disease Management (IDM) programs.
Appendix 3F	Awareness and compliance	Grower survey findings on awareness of and compliance with resistance management strategies, irrigation water testing for AMR indicators, food safety certification coverage, and IDM

		adoption.
	Parameter Workbooks	Estimated and calculated parameter sheets with full probability distributions, sources/references, and notes for every parameter across all six SLRA models (human health and plant health, three crops each).

Photos/images/other audio-visual material (see appendix for more pictures)

The project was showcased at the Hort Connections Conference (June 2026) through a dedicated industry exhibition booth, providing an opportunity to communicate project objectives, present key findings, and demonstrate the practical application of the developed risk assessment framework to growers and industry stakeholders. The conference served as an important platform for knowledge transfer, facilitating discussions on the management of antimicrobial and agrochemical resistance risks and the potential application of the project's outcomes across Australian vegetable supply chains.

Participation in the conference also strengthened industry engagement by establishing new relationships with growers, harvesting and post-harvesting businesses, accredited laboratories, and other supply chain partners. These interactions confirmed strong industry interest in the project's outcomes and identified opportunities for future collaborative research and technology development. Several stakeholders expressed interest in participating in a subsequent phase focused on developing practical risk management strategies, decision-support tools, and innovative approaches to mitigate chemical resistance and enhance the long-term sustainability and resilience of Australian vegetable production.



Outcomes

Outcome summary

Outcome	Alignment to fund outcome, strategy and KPI	Description	Evidence
Achieved	Deliverable 1: review the current evidence of antimicrobial resistance in Australian levy vegetables.	1.1 Survey the main companies in the agricultural chemicals industry (e.g., Bayer, BASF, Syngenta, Corteva, Nufarm) to identify reports/records of resistance (in plant and human pathogens) in Australian levy vegetables and related (e.g., rotation/nearby) horticultural crops. 1.2 Survey key researchers to identify reports/records of biocide and pesticide resistance in Australian levy vegetable crops. 1.3 Combine the findings into an article summarising the situation for Australian levy vegetables and reflect on international perspectives and the overall results of the project for industry magazines (VegeNotes or Vegetables Australia).	Appendix 1A: Deliverable 1.3: A review of evidence for antimicrobial resistance in Australian levy vegetable crops. Appendix 1B: Deliverable 1.3: VegeNotes #1 Staying Ahead of Antimicrobial Resistance (AMR): Protecting Australian Levy Vegetable Crops and Markets.
Achieved	Deliverable 2: qualitative estimate of potential impact of AMR on key levy vegetables.	2.1 Conduct a literature review of existing risk assessment methodologies for AMR and chemical-resistant pathogens in levy vegetables. 2.2 A review of data systems and data governance standards across supply chain through discussions with stakeholders conducted through online activities and meetings. 2.3 Collect and compile relevant economic and	Appendix 2A: Deliverable 2.1 and 2.7: <i>Risk Assessment Frameworks for Antimicrobial Resistance and Chemical Co-selection in Ready-to-Eat Vegetables: A Critical Review</i> Appendix 2B: Deliverable 2.2: <i>Review of Data Systems and Data Governance Standards Across the Australian Vegetable Production Supply Chain</i>

		trade data for the selected levy vegetables. 2.4 Conduct meetings to gather industry and consumer perspectives and estimates of the economic impact of AMR on the industry. This will involve meetings at the producer level (one in Queensland and one in West Gippsland-Melbourne metro, chosen based on the volume produced to serve Australia's two largest population centres), and meetings at the wholesaler/consolidator level (again, one in Queensland and one in West Gippsland-Melbourne metro, chosen based on production volume). 2.6 Consolidate the findings into an industry facing factsheet suitable for publication by the Vegetable industry communications program (VG22000) and the VEGNET 3.0 program (VG21000) which summarizes project findings and recommendations, including perceived benefits of adding additional pre- and post-harvest AMR and chemical-resistant pathogens management activities to existing practices. 2.7 Combine the findings into a peer-reviewed journal publication.	Appendix 2C: Deliverable 2.3: <i>Economic and Trade Data for Selected Levy Vegetables (Bagged Leafy Salad Vegetables, Carrots and Cucumbers)</i> Appendix 2D: Deliverable 2.4: <i>Exploring the Potential for Antimicrobial Resistance in Ready-to-Eat Vegetables: A Farmer-Level Scoping Study</i> Appendix 2E: Deliverable 2.5: <i>Grower Engagement and Knowledge Dissemination Activities</i> Appendix 2F: Deliverable 2.6: <i>VegeNotes #2 (submitted to AusVEG in March for publication in the Spring 2026 follow-up edition of the magazine): Antimicrobial Resistance in Ready-to-Eat Vegetables: What We Know, What We Don't, and What We Can Do. Contacts: Jessica Muller (AusVEG) and Rosalie Daniel (AusVEG).</i> Appendix 2G: <i>VegeNotes #3 (submitted to AusVEG in March for publication; however, the decision was made not to publish this VegeNote). Economic and Trade Analysis of Selected Levy Vegetable Crops: Bagged Leafy Salads, Carrots, and Cucumbers. Contacts: Jessica Muller (AusVEG) and Rosalie Daniel (AusVEG).</i>
Achieved	Deliverable 3: in consultation with various industry partners through the meetings and focus groups, compile a relative risk assessment for levy vegetables, focusing on	3.1 Identify the supply chain for the selected crops, from production to packhouse and processing (Table 1). 3.2 Identify and quantify	Deliverable 3-G A-F: This deliverable reports the findings of a modular screening-level risk assessment (SLRA) examining AMR risks

	both pre- and post-harvest management of AMR.	the value chain from production to packhouse and processing. The recent/current Senate inquiry into supermarkets could provide valuable insights here. 3.3 Identify the key pathogens where AMR could spread at each stage of the production cycle. 3.4 Determine the points at which AMR pathogens might arise/be introduced into the system (e.g., when water is used in the growing cycle, pesticide application for pest control, accidental spray drift, possible product misuse, disposal of unwanted biocides/pesticides). 3.5 Quantify potential impacts using a high (screening)-level risk assessment based on key (reference) pathogens. 3.6 Map risk pathways to identify potential control points and quantify the risks through the supply chain to identify high-risk (pathogen resistance/financial) scenarios (Table 1). 3.7 Identify biocidal and fungicidal products that may increase AMR risks through the supply chain. CRC SAAFE Project Agreement [P012 - Risk assessment of antimicrobial resistance in the vegetable industry] Page 11 3.8 Identify behaviours and practices that encourage the emergence and spread of resistant organisms at each step in the supply chain. 3.9 Document the	across the Australian horticultural supply chains for three levy crops: leafy greens, cucumbers, and carrots. Two parallel risk pathways were assessed for each crop: (1) human health risk from extended-spectrum beta-lactamase (ESBL)-producing <i>Escherichia coli</i> on fresh produce; and (2) plant health risk from reduced agrochemical efficacy due to resistance in target plant pathogens. The assessment identified the key pathogens and resistance mechanisms at each supply chain stage, mapped points of AMR introduction and amplification, and used Monte Carlo simulation to produce risk pathway rankings and directional risk characterisations for each scenario. Sensitivity figures, and detailed methodology are provided in Appendix. The most consistent finding across all six models is that pre-production inputs—seed, nursery material, irrigation water quality, and soil inoculum burden—are the primary determinants of AMR outcomes for both risk pathways. This has direct implications for where grower and industry management effort is best directed.
--	--	--	--

		existence or otherwise of industry stewardship programs at each step in the supply chain concerned with reducing the risk of selecting for AMR pathogens. 3.10 Document the levels of understanding and compliance at each level with any relevant stewardship programs (e.g., FRAC guidelines on fungicide rotation). 3.11 Combine the findings into a final report identifying strategies, practices and recommendations for further research and adoption of international best practices in Australia.	
--	--	--	--

Recommendations

The findings of this project demonstrate that antimicrobial resistance (AMR) and resistance to bactericides and fungicides represent emerging risks to the Australian vegetable industry that require coordinated, proactive management. Although relatively few published reports of resistance have been documented in Australian levy vegetable crops, the review found that this reflects a lack of systematic surveillance rather than evidence of a low level of resistance. Across the project, the literature review, industry consultation, data governance review, economic assessment, grower scoping study, extension activities, and screening level risk assessment consistently identified substantial knowledge gaps, fragmented surveillance, and limited coordination between research, industry and government. At the same time, the project demonstrated that Australia possesses strong food safety systems, internationally recognised quality assurance programs, and established resistance management frameworks that provide an excellent foundation for integrating AMR monitoring without creating unnecessary regulatory burden.

The recommendations presented below provide a strategic framework for strengthening Australia's preparedness for AMR in vegetable production. They combine immediate actions that can be implemented using existing industry structures with longer-term research and policy priorities that will support sustainable disease management, protect market access, maintain the effectiveness of crop protection products, and safeguard public health through a One Health approach.

Establish coordinated national surveillance

The highest priority emerging from this project is the establishment of a coordinated national surveillance program for antimicrobial resistance and crop pathogen resistance within Australian vegetable production. Deliverable 1 identified only fifteen published reports of fungicide or bactericide resistance in Australian levy vegetables, while consultation with CropLife Australia, the Expert Committee on Fungicide Resistance (ECFR), the Australasian Plant Pathology Society (APPS), and leading plant pathologists found little evidence of coordinated monitoring or publicly accessible surveillance data. This contrasts strongly with Australia's grains and viticulture industries, where dedicated resistance surveillance networks provide regular reporting, diagnostic support, and evidence-based management recommendations. A national surveillance program should adopt a farm-to-fork approach and include monitoring of irrigation water, soils, composts, biosolids, growing media, seed and nursery material, production environments, harvested produce, processing facilities, and retail products. Surveillance should include antimicrobial-resistant microorganisms, antimicrobial resistance genes (ARGs), mobile genetic elements (MGEs), and resistance to fungicides and bactericides affecting economically important vegetable pathogens. Initially, monitoring should prioritise ready-to-eat leafy vegetables, carrots and cucumbers because these commodities combine high production value with elevated food safety significance and were identified throughout the

project as priority commodities for risk assessment. Standardised national sampling protocols, laboratory methodologies, and reporting procedures should be developed to enable comparisons across regions and production systems. A centralised national database should capture confirmed resistance detections and facilitate early warning of emerging threats. Such a system would support evidence-based decision-making by growers, industry, researchers and regulators while providing the data required to refine future quantitative risk assessments.

Build a national horticultural resistance network

The project demonstrates a clear need for an Australian horticultural resistance network equivalent to the Australian Fungicide Resistance Extension Network (AFREN). Such a network should integrate researchers, diagnostic laboratories, government agencies, universities, industry organisations, CropLife Australia, Hort Innovation, SAAFE^{CRC}, extension specialists, agronomists and growers within a collaborative national framework. The network should coordinate surveillance, diagnostic testing, data sharing, extension activities, and stewardship programs while facilitating rapid communication of emerging resistance issues. It should also maintain national expertise in pathogen diagnostics, fungicide sensitivity testing, genomic surveillance and AMR monitoring. Importantly, the network should provide growers with practical management recommendations based on current evidence rather than relying solely on international information that may not reflect Australian production systems. Developing such a collaborative model would significantly improve Australia's ability to detect emerging resistance early, respond before resistance becomes widespread, and protect the efficacy of existing crop protection products.

Integrate AMR into existing industry systems

One of the major findings of Deliverable 2.2 was that Australia already possesses highly effective food safety and quality assurance systems. Freshcare, HARPS, GLOBALG.A.P., SQF, BRCGS and FSANZ requirements collectively provide comprehensive governance covering traceability, water quality, hygiene, sanitation, environmental monitoring, staff training and documentation. Rather than creating new certification requirements, AMR monitoring should be integrated within these existing systems. Records relating to irrigation water, composts, biosolids, pesticide use, sanitation, environmental monitoring and corrective actions can readily accommodate AMR-related information. Incorporating AMR surveillance into established quality assurance systems would minimise additional compliance costs while providing an efficient mechanism for collecting nationally consistent information. Similarly, existing fungicide stewardship programs developed by CropLife Australia and FRAC should be expanded to include broader antimicrobial stewardship principles. This integrated approach recognises that resistance management is most effective when incorporated into routine farm management rather than treated as a separate activity.

Strengthen stewardship across the production chain

The project demonstrated that resistance selection is influenced by far more than antibiotic exposure alone. Fungicides, bactericides, herbicides, disinfectants and heavy metals all have the potential to contribute to chemical co-selection and the persistence of resistant microorganisms. Consequently, stewardship programs should adopt a broader systems perspective encompassing both human health and plant health. Growers should continue implementing integrated pest and disease management strategies that minimise reliance on repeated applications of single chemical groups. Evidence-based FRAC mode-of-action rotation should become standard practice across all vegetable production systems, avoiding consecutive use of the same fungicide group within or between seasons. Stewardship programs should continue promoting resistant cultivars where available, cultural disease management practices, sanitation, biological control, and improved crop monitoring to reduce unnecessary chemical inputs. The project also identified seed and nursery hygiene as one of the highest leverage intervention points across multiple quantitative risk assessment models. Strengthening certification and hygiene standards for seed lots, transplants and nursery production therefore offers an efficient means of simultaneously reducing both plant health and human health risks.

Prioritise research where uncertainty is greatest

Although the project established a strong evidence base, it also highlighted several important knowledge gaps requiring future investment. The most immediate priority is to quantify the occurrence of ESBL-producing *E. coli*, ARGs and resistant microorganisms within Australian irrigation water, soils, composts, biosolids and nursery production systems. These parameters dominated the uncertainty within the quantitative human health models and represent the highest-value investment for improving future risk assessments. Similarly, baseline fungicide sensitivity surveys should be undertaken for priority pathogens affecting carrots, cucurbits and leafy vegetables. These surveys should establish current resistance frequencies and provide benchmarks for future surveillance. Long-term monitoring would allow changes in resistance prevalence to be detected before significant disease control failures occur.

Field validation studies are also required to link laboratory resistance detection with actual disease control outcomes under

commercial conditions. Establishing practical efficacy thresholds will substantially improve the interpretation of surveillance results and strengthen future recommendations provided to growers.

Future research should also investigate the influence of landscape characteristics, seasonal variability, irrigation sources, climate, and surrounding land use on AMR risk. Incorporating these factors into future iterations of the quantitative models would allow the development of location-specific risk assessments capable of supporting precision risk management.

Expand extension and industry engagement

The extension activities undertaken during this project demonstrated that growers currently regard AMR as a relatively low priority compared with fungicide resistance, profitability and production efficiency. Nevertheless, the project also demonstrated that growers possess strong knowledge of resistance management through existing fungicide stewardship programs. Future extension should therefore build upon this existing understanding rather than introducing AMR as an entirely new concept. Integrating AMR messages into established crop protection programs will improve acceptance while reinforcing the relationship between responsible chemical use, food safety, environmental sustainability and long-term productivity. Practical extension materials should focus on priority actions identified by the quantitative risk assessment, including irrigation water monitoring, seed hygiene, nursery biosecurity, refrigerated storage where appropriate, consumer washing advice, integrated disease management, and responsible chemical stewardship. Continued collaboration with VegNET, AUSVEG, agronomists and crop consultants will be essential for translating research findings into routine commercial practice.

Support policy through a One Health approach

The project consistently demonstrated that AMR within vegetable production cannot be considered solely as a food safety issue or solely as a crop protection issue. Rather, it represents a One Health challenge involving interactions between environmental reservoirs, agricultural production systems, plant pathogens, foodborne microorganisms, consumers and international trade. Future policy should therefore integrate horticulture more explicitly within Australia's National Antimicrobial Resistance Strategy. Surveillance, environmental management, food safety, agricultural stewardship and public health activities should be coordinated across government agencies and research organisations. This integrated approach will strengthen preparedness for emerging resistance threats while supporting Australia's reputation as a supplier of safe, high-quality fresh produce.

Sustain long-term investment

Finally, the project highlights the importance of sustained investment in surveillance, diagnostics, research, extension and workforce capability. Vegetable crops at high or medium risk account for more than AUD \$2 billion annually in production value, while the commodities prioritised within this project contribute more than one-quarter of Australia's vegetable industry by value. Protecting these industries from emerging resistance therefore represents an important investment in national food security, export competitiveness and grower profitability. Continued collaboration between Hort Innovation, SAAFCRC, CropLife Australia, research organisations, government agencies and industry partners will be essential to build the scientific evidence, surveillance infrastructure and extension capability required to manage AMR proactively. Investment in coordinated surveillance and stewardship today will substantially reduce future economic losses, preserve the effectiveness of existing crop protection tools, support evidence-based policy, and strengthen the resilience and sustainability of Australian vegetable production for decades to come.

The project's findings were actively disseminated through presentations and engagement with growers, industry stakeholders, government representatives, and researchers at industry meetings and the Hort Connections Conference (June 2026). The conference provided a valuable opportunity for the project team to host a dedicated exhibition booth, facilitating direct engagement with growers, industry representatives, researchers, and prospective project partners. The event served as an effective platform to communicate the project's objectives, present key findings from AMR risk assessment, and demonstrate the practical application of the project's risk assessment framework and decision-support tools. Discussions focused on the implications of AMR and chemical resistance for the Australian vegetable industry, current knowledge gaps, and opportunities to strengthen surveillance, stewardship, and sustainable crop protection practices. The conference also enabled the establishment of new collaborative relationships with growers, harvesting and post-harvest service providers, accredited diagnostic laboratories, technology developers, and other industry organisations. Several stakeholders expressed strong interest in participating in a future phase of the project aimed at developing innovative surveillance approaches, diagnostic tools, and integrated management strategies to address antimicrobial and chemical

resistance, strengthen evidence-based decision-making, and enhance the long-term sustainability, resilience, and competitiveness of the Australian vegetable industry.

Referred scientific publications

Journal article

Jowenna X. F. Sim, Claire Hayward, Mark Drew, Fran Lopez-Ruiz, Sukhvinder Pal Singh, Nicholas J. Ashbolt and Barbara Drigo. ***Risk Assessment Frameworks for Antimicrobial Resistance and Chemical Co-selection in Ready-to-Eat Vegetables: A Critical Review***. Accepted on 1 September 2026 in Trends in Food Science & Technology.

Intellectual property

No project IP or commercialization to report

Acknowledgements

The project team sincerely thanks the many vegetable growers, industry representatives, government agencies, researchers, and stakeholders who generously contributed their time, knowledge, and expertise throughout this project. We are especially grateful to the growers who participated in surveys, hosted farm visits, and openly shared their production practices, experiences, and perspectives despite the significant operational and seasonal pressures facing the industry. Their willingness to engage with the project has been fundamental to ensuring that the research remains relevant, practical, and aligned with industry needs.

We gratefully acknowledge the outstanding support provided by **AUSVEG**, particularly **Zarmeen Hassan** and her team, whose guidance, industry connections, and commitment were instrumental in the design, implementation, and successful completion of this study. Their assistance in facilitating industry engagement and knowledge exchange greatly strengthened the quality and impact of the project.

We also acknowledge the **Cooperative Research Centre for Solving Antimicrobial Resistance in Agribusiness, Food and Environments (SAAFE^{CRC})** team for their ongoing administrative, organisational, and operational support throughout the project. Their professionalism and commitment ensured the smooth delivery of project activities and facilitated effective collaboration between all project partners.

We extend our sincere appreciation to **Dr Sukhvinder Pal Singh** for his wisdom, scientific insight, encouragement, and unwavering guidance throughout the project. His strategic advice and thoughtful leadership have been invaluable in shaping the direction and outcomes of this work.

Our sincere thanks are also extended to **Bianca Cairns** and the entire **Hort Innovation** team for their continued support, constructive advice, and commitment to advancing research that strengthens the sustainability, productivity, and resilience of the Australian vegetable industry.

Finally, we thank all project collaborators, advisory group members, research partners, and industry stakeholders whose contributions, expertise, and commitment made this project possible. We greatly value the collaborative relationships established during this project and look forward to continuing to work together to advance AMR research, stewardship, and innovation across Australia's vegetable industry.

Disclaimer

This publication is produced by Australia's Cooperative Research Centre for Solving Antimicrobial Resistance (AMR) in Agribusiness, Food and Environments (SAAFE CRC) which is owned and operated by SAAFE Limited.

SAAFE CRC is supported through funding from the Australian Government as well as contributions from valued research and industry partners. We gratefully acknowledge the support of our funding partners, whose contributions have enabled the research and development presented in this work. The views and opinions expressed in this publication are those of the authors and do not necessarily reflect those of the Australian Government or any other funding bodies.

The information contained in this publication is general in nature. While every effort has been made to ensure the accuracy and reliability of the information contained herein, SAAFE CRC makes no warranties or representations, express or implied, about the completeness, correctness, or suitability of the information for any particular purpose.

SAAFE CRC (which includes employees, consultants, affiliated staff and students of SAAFE Limited) and the authors or contributors of this publication expressly disclaim, to the maximum extent permitted by law, all responsibility for any loss, damage or consequences arising directly

or indirectly from any act or omission made in reliance on the contents of this publication. This disclaimer applies regardless of whether such loss or damage was caused by negligence on the part of SAAFE CRC or any of its associated individuals.

This research has been conducted in accordance with the principles of the Australian Code for the Responsible Conduct of Research, ensuring integrity, rigour, and ethical standards throughout the research process. The authors declare no conflict of interest in relation to this research and its publication.

© 2026 SAAFE Limited. This publication is protected by copyright.

This work is licensed under a Creative Commons Attribution Non-Commercial 4.0 International Licence (CC BY-NC 4.0). You are free to share and adapt the material for non-commercial purposes provided that appropriate credit is given, a link to the licence is provided and any changes made are indicated. Commercial use of this material is not permitted without prior written permission of SAAFE CRC. Requests and enquiries relating to rights and reproduction of this work should be addressed to team@crdsaafe.com.au

Please direct any feedback on this publication to SAAFE CRC via www.crdsaafe.com.au/contact, or your SAAFE CRC contact.

SAAFE^{CRC}

www.crcsaafe.com.au
enquiries@crcsaafe.com.au
+61 8 8302 3617
PO BOX 66, Pooraka 5095



Australian Government
Department of Industry,
Science and Resources

**Cooperative Research
Centres Program**

This project is supported by the Australian Government
Department of Industry, Science and Resources through
the Cooperative Research Centres Program.