GUIDE TO UNDERSTANDING AND MANAGING

BACTERIAL DISEASES AFFECTING AUSTRALIAN VEGETABLE CROPS

Hort Innovation
Strategic levy investment

VEGETABLE FUND

Queensland Government

2022

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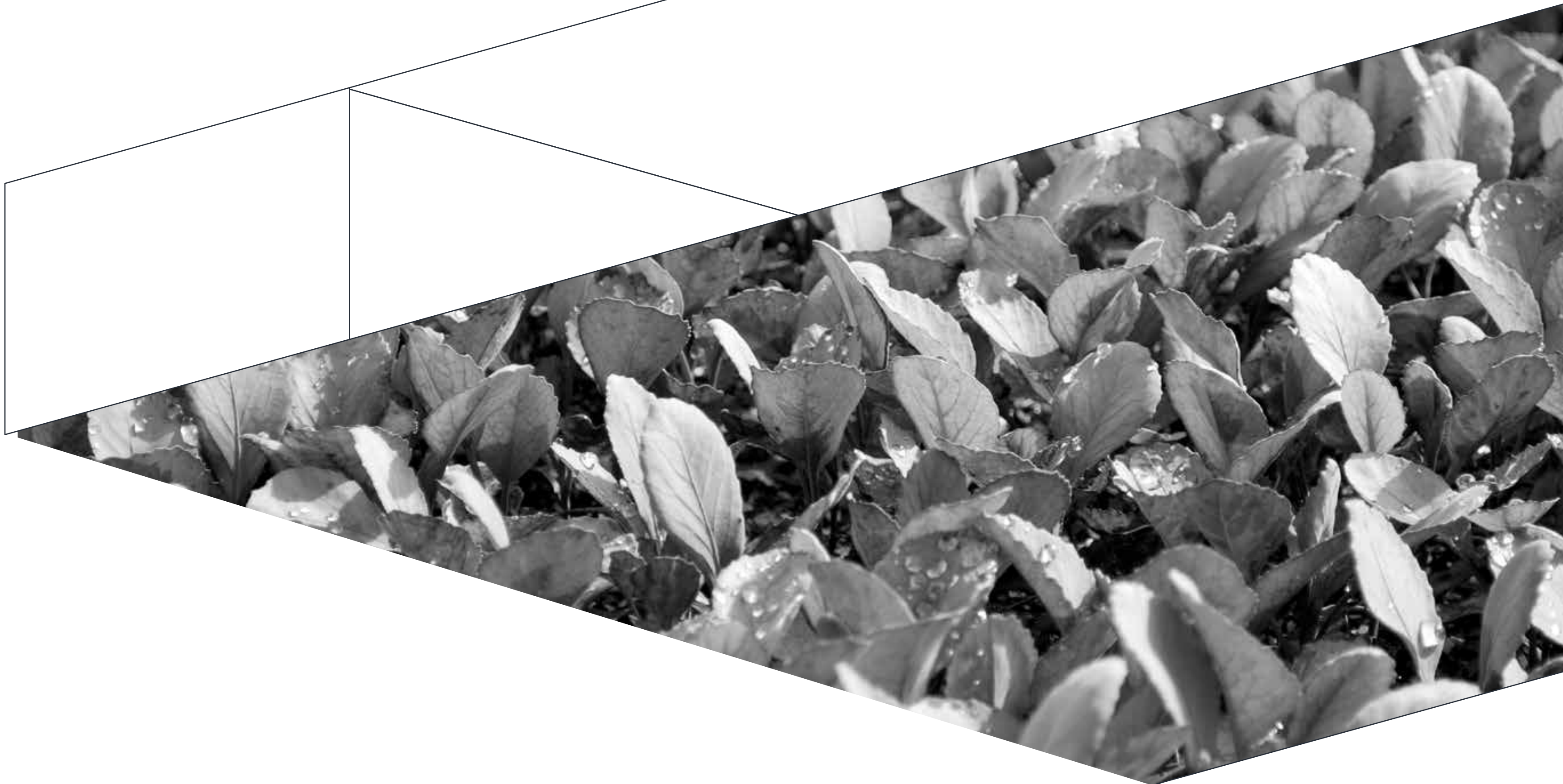

First published May 2022

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FUNDING

Hort Innovation Project VG16086 'Area wide management of diseases: viruses and bacteria'. This project has been funded by Hort Innovation using vegetable industry levies and contributions from the Australian Government with co-investment from the Queensland Department of Agriculture and Fisheries; Victorian Department of Economic Development, Jobs, Transport and Resources; The Northern Territory Department of Primary Industry and Resources; the Western Australia Department of Primary Industries and Regional Development and the University of Tasmania. It is supported by a second project led by the New South Wales Department of Primary Industries and similarly funded by Hort Innovation using vegetable industry levies and contributions from the Australian Government and NSW DPI.

Hort Innovation Strategic levy investment | VEGETABLE FUND

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

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GUIDE

INTRODUCTION

Bacterial diseases cause significant impacts to vegetable production nationally. Disease outbreaks are sporadic and influenced substantially by weather conditions. This guide provides information on the most common bacterial diseases in Australian vegetables, how to identify them and what management is available for their control. Bacterial diseases can affect all production systems from open field to high-tech protected cropping.

This disease guide covers bacteria already present in Australia. There are many other bacterial diseases present overseas which could enter Australia. It is important to be aware of these diseases and send samples for diagnoses if you suspect a new disease has arrived. For more information on exotic diseases please visit the Plant Health Australia website (https://www.planthealthaustralia.com.au/).

HOW TO
USE THIS GUIDE

This guide is divided into different sections. The first section outlines basic bacterial disease identification and general management. The next section has specific details on the major bacterial diseases affecting Australian vegetable crops including what they look like and additional control methods for management if known. The major production areas for each jurisdiction, outlining the common crops grown and the bacterial diseases likely to be found in that area, are provided in the last section. Further resources are provided in the appendices.

Crop debris

Seed

Water (Irrigation, dew, etc)

Storm (wind-driven rain, hail)

People/ equipment

Insects

Cover/ rotational crop

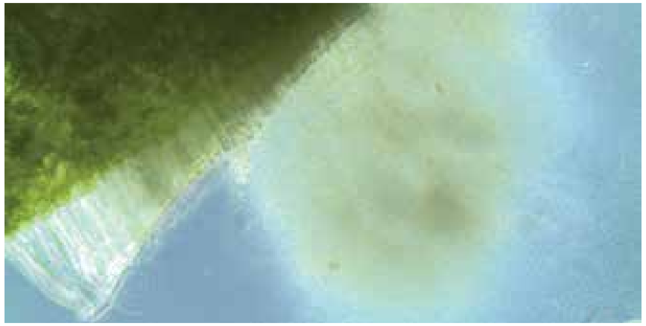
Soil

BACTERIAL DISEASE **IDENTIFICATION**

HOW DO I KNOW IF I HAVE A BACTERIAL DISEASE IN MY VEGETABLE CROP?

Bacterial diseases in the field can be identified by looking at plant symptoms but these can be confused with other diseases and abiotic factors such as water stress and sunburn. Multiple diseases and/or disorders could be present and accurate identification is key to effective control.

Plant symptoms along with other information on location of crop, method of cultivation, irrigation method, chemical application, recent climatic conditions, the pattern and incidence of the disease within the crop, block history (previous diseases, rotations, cover crops etc) and examination for the presence of bacterial ooze or fungal structures all provide clues to the cause(s).



Bacteria oozes out of a spot.

While these observations are useful for guiding identification, it is still important to confirm the cause with more formal diagnostics through a qualified laboratory. Many diseases and nutritional conditions can look similar and will require diagnostic testing to accurately identify them.

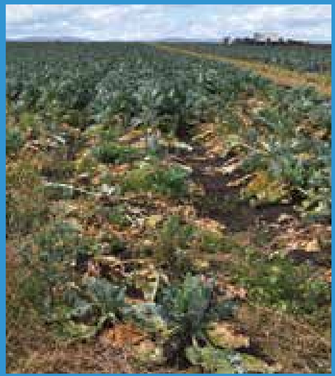
THE FOLLOWING GENERAL OBSERVATIONS IN THE FIELD MAY INDICATE BACTERIAL DISEASE:

Fungicides are not effective

Significant rotting of plant tissues, typically the crown and stems

Green wilts

Leaf spots that may appear angular with yellow halos



Disease appears after periods of rainfall and/or hailstorms

WHICH BACTERIA IS IT?

There are five major groups of bacteria that affect vegetable crops, based on the symptoms they cause. Almost all these diseases can occur in all growing districts, however, some diseases are more commonly found in some districts. For a list of common diseases in each major Australian growing district refer to page 30.

01 FOLIAR-INFECTING BACTERIA: SPOTS AND BLIGHTS

Spotting is a common symptom of bacterial disease affecting foliage and can be easily seen on leaves, flowers, fruits, and stems. Spots occur at the site of infection. On leaves they are often angular, water soaked and confined between leaf veins. Some bacteria induce a yellow halo around this site of infection. Spots may merge causing large areas of dead tissue and give a blighted appearance. There is a wide variety of spots seen in vegetable crops. Shape, colour, and size will vary depending on the crop, the bacteria infecting it, the environmental conditions, and the severity of the disease.

Common foliar infecting bacteria of vegetables are the *Pseudomonas syringae* complex and other species in the *Pseudomonas* genus such as *P. viridiflava*, *P. cichorii*, *P. corrugata*, *P. marginalis*, and *P. mediterranea*. The *P. syringae* complex alone includes over 50 different strains called pathovars, each of which has a limited host range. These pathovars are further divided into races which infect only some susceptible varieties of a vegetable crop.

Xanthomonas species, pathovars and races are another common group which affect vegetables. This group includes *X. campestris* pathovars which infect all brassica crops, the Xanthomonad complex of species (*X. arb*oricola, *X.* euvesicatoria, *X. gardneri, X. perforans* and *X. vesicatoria*) that cause bacterial leaf spot diseases in solanaceous crops (tomato, capsicum and chilli), as well as *X. vitians, X. phaseoli, X. pisi* and *X. curcurbitae* which affects lettuce, beans, pea and cucurbits, respectively. Note that the names of these species vary in different scientific and historical literature so be aware they may appear under different names. For example, *X. vitians* is also known as *X. hortum* pv. *vitians*.

02 VASCULAR WILT BACTERIA

Vascular wilts are caused by bacteria that infect the xylem tissue within the plant stem. This causes a disruption to movement of water and nutrients in the plant which eventually leads to wilting. This symptom is best seen during the day when water usage by the plants is highest. Hot conditions and fruit load also increase wilting symptoms. Advanced infections typically result in plant death.

Vascular wilt in vegetable crops (solanaceous, cucurbit and legume crops) are caused by the *Ralstonia* species complex (*R. pseudosolanacearum* biovars and *R. solanacearum*). *Clavibacter michiganensis* subsp. *michiganensis* causes vascular wilts in Solanaceae crops, primarily tomatoes. Note here the terms biovars and subspecies which are used to distinguish bacterial strains below the species level. These distinctions can have important biological and biosecurity implications. For example, Australia does not have all the strains of *R. pseudosolanacearum* that occur overseas. These affect a wider range of vegetable crops, and there is an important subspecies of *C. michiganensis* not present in Australia which causes a serious disease (ring rot) of potatoes overseas. *Curtobacterium flaccumfaciens* pv. *flaccumfaciens* is an emerging vascular wilt disease in edible legumes including French bean.

Tomato canker

03 SOFT ROT BACTERIA

Another broad range of bacterial species cause soft rot symptoms in a variety of vegetable crops. These are mostly species of *Pectobacterium* and *Dickeya*. These bacteria secrete a pectate lyase which is an enzyme that destroys the plant cell walls, thus causing plants to rot. Infection starts with windblown rain or water splashing onto damaged tissue due to insect feeding, mechanical operations, other diseases, nutritional imbalances or environmental stresses. Initial symptoms show small water-soaked lesion that expand rapidly under warm and wet conditions. The infected tissues become soft, mushy, and slimy and have a putrid smell. Fleshy stem and fruit flesh rots leave skin as a hollow shell. Direct contact with infected fruit or contaminated wash water with bacterial ooze result in heavy economic losses in transit and storage. Occasionally species of *Pantoea* will also cause soft-rots in a similar way, however, these diseases are much less common.

The *Pectobacterium* species group is comprised of a number of different species that cause soft rots in a range of hosts, and includes *Pectobacterium atrosepticum*, *P. wasabiae, P. carotovorum, P. parmentieri* and *P. brasiliensis*. The *Dickeya* species group includes *D. chrysanthemi, D. dianthicola*, and *D. zeae. Dickeya* species also have a wide host range and can survive on alternate crops such as ornamentals which then infect the new vegetable crop the following year. Many of these bacteria were previously called *Erwinia*.

04 TUMOUR INDUCING BACTERIA

Agrobacterium tumefaciens (synonym *Rhizobium radiobacter*) and *Rhodococcus fascians* (synonym *Curtobacterium fascians*) induce tumours such as galls and proliferating roots in a range of crop plants. These bacteria can affect a range of vegetable crops including brassicas, cucurbits and solanaceous vegetables. Greenhouse cucumbers, tomatoes, eggplants and zucchini can be affected by certain *Rhizobium* species causing a disease called Crazy Root (Hairy Root) where roots proliferate, the plant becomes more vegetative and produces fewer fruit.

05 PHYTOPLASMA: TOMATO BIG BUD DISEASE

Phytoplasma are very different to the other bacterial pathogens that affect vegetable crops. They are obligate pathogens which means they don't survive outside their plant or insect hosts. The mode of infection is more like plant viruses than other bacterial pathogens of plants. Phytoplasma can affect most vegetable crops but are very sporadic in their incidence.

Agrobacterium infection of cauliflower

WHERE CAN I SEND SAMPLES **FOR DIAGNOSTIC TESTING?**

A range of diagnostic services are available in Australia for accurate identification of disease agents. Sending samples to your state or territory diagnostic service is recommended. These services are listed in Appendix 1 with information on how to collect and package samples (see Appendix 2).

BACTERIAL DISEASE **IDENTIFICATION**

HOW DO BACTERIA INFECT PLANTS?

Bacteria are motile and exhibit chemotaxis. This means they are free moving (motile) and actively move towards chemical triggers (chemotaxis). They move by swimming using flagella (tails) to propel themselves. This is why rain or free water is such an important factor in bacterial disease development and spread. In the presence of water (or other liquids) the bacteria swim towards natural openings such as stomata or wound sites they have sensed from chemicals released by the plant. Bacteria multiply to very high numbers in infected plants and are readily transferred, causing further infections. This is particularly fast if environmental conditions are conducive for disease such as persistent wet weather, overhead irrigation or high humidity within the crop canopy.

Foliar bacteria (*Xanthomonas* or *Pseudomonas*) typically infect stomata, hydathodes and other natural openings on leaves, petioles, stems and fruit. A single spot can contain about 10^7 to 10^{10} bacterial cells per ml. When these spots become wet huge numbers of bacteria are released leading to more infections. This explains why wet weather can rapidly turn a very low incidence of bacterial disease in a crop to a very high one. Protectants reduce infections under dry conditions; however, as coverage into wounds or natural openings is poor, when conditions are wet the bacteria actively swim towards the uncoated wounds and openings.

Vascular wilt bacteria (*Ralstonia, Clavibacter* and *Curtobacterium*) *Ralstonia* and *Clavibacter* infect the xylem and enters the plant via roots through wounds and at the junctions where roots emerge or branch. Infection of stems via wounds is through contact with soil or infested irrigation water or through pruning and other crop maintenance activities. The bacteria multiply to about 10^9 bacterial cells per gram of stem tissue and are actively shed from live infected plants via the roots and from decaying infected plants. The bacterial cells can then be spread in irrigation water or rainfall run-off. *Clavibacter* differs from *Ralstonia*, in that it survives less well in the environment thus soil and irrigation water are a lower risk as sources for new disease outbreaks. For both diseases, contaminated planting stakes and wires can cause carryover between crops if they are not cleaned and disinfected between crops. *Curtobacterium flaccumfaciens* pv. *flaccumfaciens* is an emerging vascular wilt disease in edible legumes including French bean. It is best managed through use of seed certified free of the bacterium and degradation of crop debris.

Soft rot bacteria (*Pectobacterium*, *Dickeya* and *Pantoea*) infect via wounds or natural openings. These species are highly adapted to the environment and survive well on the outside of foliage or roots, in the soil and on decaying plant material. Once these bacteria infect a plant, they secrete enzymes to dissolve the pectin in plant cell walls and utilise cell contents as a source of nutrients. This gives the typical 'soft-rot' symptom as the plant loses its cellular structure. As the plants decay from infection, the bacteria multiply and are released back into the environment. They can then be spread in irrigation water or run-off rainfall. Many species are also spread by insects feeding or landing on rotting plant tissues and then transferring bacteria to healthy plants.

Tumour bacteria are usually soil-borne and infect through the roots, crown or lower stem. They can be spread in soil and water. **Phytoplasma** infections occur when an insect vector, typically leafhoppers or planthoppers, feed on the vascular tissues of a plant.

WHERE DO THE BACTERIA COME FROM?

The greatest source of bacteria for spread within a crop will be infected crop plants. This means reducing initial introduction of the bacteria into the crop provides the best management of disease. These primary infected plants will not recover from disease and will continue to release bacteria for their lifespan.

Bacterial diseases can enter crops via several pathways. Many of the bacteria are seed-borne so it's important to source certified seed from reputable companies or treat the seed. Clean planting material will provide high confidence in reducing risk of primary introduction of bacterial diseases into crops.

Many of these bacteria also survive in crop trash and infect subsequent plantings if the trash is not completely degraded. Some survive in the soil, for varying lengths of times. Diagnostic confirmation of which bacterium is causing disease will help with evaluating risk of further disease outbreaks from soil and/or infected crop trash.

WHAT SHOULD I DO?

Disease management should start prior to planting by sourcing clean planting material. Source certified seed and consider hot water treatment to further reduce risk. When using seedlings, consult with your nursery on options to have seed treated. Appendix 3 has a list of recommended treatments.

If disease outbreaks occur, restrict access in that area and implement strict hygiene measures for staff and equipment movements.

FOR FIELD CROPS WHERE POSSIBLE

- Check seedlings are free from insect pests and diseases prior to planting
- Rotate with non-host crops such as cereal or non-susceptible hosts
- Plant on well drained land, raising the planting bed height, and reduce plant density
- Take care when handling or planting seedlings to minimise plant injury, as wounds allow bacterial entry
- Avoid long hours of leaf wetness
- Water crops earlier in the day to avoid overnight wetness
- Avoid overhead irrigation where possible
- Ensure weeds are well controlled around and in crops
- Control insects particularly chewing ones which create wound sites for infection
- Avoid transplanting in wet conditions
- Manage younger and unaffected crops first before moving into older or diseased crops to reduce risk of disease spread
- Ensure equipment is decontaminated prior to use to prevent the spread of bacteria
- Avoid working in crops when they are wet to reduce mechanical damage and transmission
- Incorporate or remove crop residues immediately after harvest, particularly where there are nearby successive plantings
- Ensure the plants receive sufficient calcium and not excess nitrogen for optimal plant health - suboptimal nutrition weakens plant defence responses
- Monitor crops regularly for nutrition and crop health for early detection and management of diseases

FOR PROTECTED CROPS WHERE POSSIBLE

- Clean and disinfect greenhouses, benches and equipment before planting
- Disinfect cutting/pruning tools
- Maintain greenhouse, equipment, and staff hygiene
- Check seedlings are free from insect pests and diseases prior to planting
- Avoid long hours of leaf wetness
- Water crops earlier in the day to avoid overnight wetness
- Avoid overhead irrigation or misting
- Monitor crops regularly for nutrition and crop health for early detection and management of diseases
- Maintain clean and weed free buffer zone around growing areas
- Dispose of crop debris away from growing areas.

- Use reputable planting media
- Establish control check stations for EC/pH/ nutrient monitoring for management
- Treat water if disease outbreaks are suspected
- Control insects particularly chewing ones which create wound sites for infection

TREATMENT OPTIONS

Prevention is currently the only option for bacterial disease management. Once infection has occurred, it is too late to save the plant. Removal of early infected plants at low disease incidence can be useful to reduce in-crop spread.

Protectants to reduce infection are registered for use in vegetable production including both chemical and biological agents. Most chemical protectants are copper based and often perform poorly if disease pressure is high (refer to Appendix 4 for more information on effectiveness of copper). Please refer to the Australian Pesticides and Veterinary Medicines Authority (APVMA) website for a list of registered products.

IS DISEASE MONITORING USEFUL?

Yes, disease monitoring is useful. It allows early intervention if needed and with time it builds knowledge about disease outbreaks. Regular monitoring with good record keeping provides a baseline on when and where diseases occurred and what management actions did or didn't work. For example, regular appearance of disease in a section of a certain block indicates presence of the bacteria in the soil at that location or it could be a low spot more prone to frost which facilitates bacterial infection through wounds.

Regular diagnostic testing of disease outbreaks value adds to the monitoring data. Symptoms can be similar for different diseases, thus getting diagnostic tests done allows the monitoring data to be linked to a specific bacterium and disease.

BACTERIAL LEAF SPOT
IN SOLANACEAE

Bacterial leaf spot (BLS) is caused by a *Xanthomonas* species complex. In Australia, this includes *X. vesicatoria, X. euvesicatoria* pv. *euvesicatoria* which infects mainly capsicum and chilli, while *X. vesicatoria* and *X. euvesicatoria* pv. *perforans* primarily infect tomato. A fourth species, *X. axonopodis* pv. *gardneri* was not detected in recent Australian surveys and is thus not known to occur here. Eggplant can also be infected by some of these bacteria but this is rare.

WHAT DOES IT LOOK LIKE?

BLS symptoms occur from seedlings through to mature plants. The tan to black spots start as small dots and grow to 2-3 mm in diameter and often have an angular appearance. The spots often merge to form large dead sections. Spots occur on leaves, stems, and calyxes. Fruit spots are present in severe infections. Severe infections can result in defoliation leading to plant death.

BLS can be easily confused with other bacterial or fungal spots. Bacterial speck (*Pseudomonas syringae* pv. *tomato*) and fungal spots (e.g. target spot caused by *Alternaria solani*) on tomato can appear almost identical to BLS. Speck is generally characterised by smaller spots that give the leaf a 'peppered' appearance. Fungal spots are often larger and less angular. Symptoms of these diseases may also be present on stems and fruit, though fruit symptoms are distinctly different from the 'bird's eye' spots typical of tomato canker caused by *Clavibacter michagenesis* pv. *michagenesis*. The only way to diagnose BLS with confidence is to get a laboratory identification.

WHERE DOES IT COME FROM AND HOW DOES IT SPREAD?

The major pathways for BLS bacteria into crops are via seed, crop debris, and nearby infected crops. There is some evidence for survival of the bacteria in weeds, although this is unlikely to be a major source for spread of bacteria into crops. The bacteria don't survive well in soil but can survive in undegraded infected crop trash. Disease development and spread is favoured by warm, humid, and wet conditions. Spread of the bacteria within and between crops is primarily through water, particularly wind-driven rain and by people or equipment when working in wet crops. Physical damage to plants, particularly in association with free water, increases bacterial infections and spread.

DISEASE MANAGEMENT

In addition to general disease management recommendations consider hot water treatment of seed (see Appendix 3), particularly for tomato and chilli where there are no host resistance genes available. Under low disease pressure, copper with ethylene bis-dithiocarbamate (e.g. mancozeb) will suppress disease, however, withholding periods for EBDC will prevent its use once fruit harvest starts. Registered biological control agents for BLS, either as separate applications or in combination with the copper treatments are also useful, as is rouging of infected plants at low disease incidence.

For capsicums, resistance genes for specific races of BLS are available and are very effective for disease control. In Australia these genes are Xcv-0, 1, 2, 3, 5, 7, 8 and 9, and are available in varying combinations, typically, 0-3, 1-3, 0-5, 1-5 and 7-9. The resistance gene number refers to the race of the bacterial pathogen that it is effective against, for example, Xcv 1 combats race 1. There are

very few chilli and tomato lines with BLS or Xcv resistance and often this has no race designation. In Australia, research in 2014-2015 identified *X. euvesicatoria* pv. *euvesicatoria* races 1 and 7 from testing of 16 local bacterial isolates. Anecdotal observations indicate more races are present in Australia and it is likely more will appear due to evolution of the bacteria or co-importation with seed. If BLS disease occurs with use of these resistant lines it is possible a new race has emerged.

PECTOBACTERIUM IN ZUCCHINI

In recent years, soft-rot of zucchini crops has emerged as an increasing problem. From 2018-2022, this disease was detected in several growing districts in Queensland and Western Australia. It is likely to be present in other areas. The disease is caused by *Pectobacterium* spp. but may have been mis-identified as *Erwinia* spp. in past outbreaks.

WHAT DOES IT LOOK LIKE?

Pectobacterium infection of zucchini typically looks like the plants are collapsing and the leaves have fallen off. Inspection of the crown area will show a rot and, in some cases, bacterial ooze maybe present. The disease can be confused with damage from high winds that have caused the leaves to be broken off. It can also be confused with the crown rot of zucchini caused by *Pseudomonas syringae* pv. *syringae*, however, this disease has so far only been recorded in Bundaberg, QLD.

WHERE DOES IT COME FROM AND HOW DOES IT SPREAD?

Pectobacterium is known to be seed-borne in some crops, however, this is not proven for zucchini. It is likely the bacterium enters crops via contaminated seed or seedlings and/or crop debris. There is little known about the survival of the bacteria in soil, however, preliminary studies indicate infection of zucchini from soil isn't a high risk. The bacteria survive in crop debris and can then reinfect a new crop, if this debris has not broken down before replanting. Disease development and spread is also not well understood. It is likely, however, to be favoured by wet conditions. Spread of the bacteria within and between crops is possibly by people or equipment when working in wet crops and anecdotal evidence indicates spread could occur by insects. Physical damage to plants, particularly in association with free water, increases bacterial infections and spread.

DISEASE MANAGEMENT

In addition to general disease management recommendations, consider hot water treatment of seed to reduce risk of primary introduction into blocks (see Appendix 3). Management of this disease requires further investigation as the effectiveness of copper and other preventative bactericides is unknown. The potential spread by insects also warrants further study before recommendations for insect control can be made. Rouging infected plants at low disease incidence is likely to have positive reductions in disease spread, provided the crop debris is removed from the block and disposed of by deep burial or incineration.

There are no known resistance genes for this bacterium in cucurbit crops.

PECTOBACTERIUM IN BRASSICAS - SOFT ROT

***Pectobacterium carotovorum* and *Pectobacterium brasiliense*. Both these bacteria cause similar infection in multiple hosts which include wombok, leafy brassicas, cabbage, cauliflower, broccoli, and radish.**

WHAT DOES IT LOOK LIKE?

Soft rot of brassicas can take two forms. The most common form is soft rot in Chinese cabbage when the disease usually starts as a basal stem rot on a more mature plant. As the disease progresses the inner leaves begin to decompose, turning into mush. The disease progresses in the base of the leaves and results in the collapse of the plant.

Soft rot can often occur as a post-harvest disease, particularly during transport and storage without refrigeration, or where exposed to warm temperatures and poor ventilation.

The second form of soft rot is head rot of broccoli and cauliflower where there is dark water-soaked decay of the surface florets.

It is suggested that head rot is a disease complex between commonly occurring pathogenic bacteria and fungi. Different combinations of these pathogens may be present displaying identical symptoms. These other pathogens include various *Pseudomonas* and *Alternaria* species.

WHERE DOES IT COME FROM AND HOW DOES IT SPREAD?

Pectobacterium is an environmental pathogen, that can survive for extended periods on healthy plants, plant trash, soil, and in water. It is readily spread by insects via contact transmission. Infection can occur when the plants are stressed or have been damaged. *Pectobacterium* is seed-borne in some brassicas so sourcing certified seed from reputable agents is very important. Additionally, hot water treatment is effective to reduce this risk.

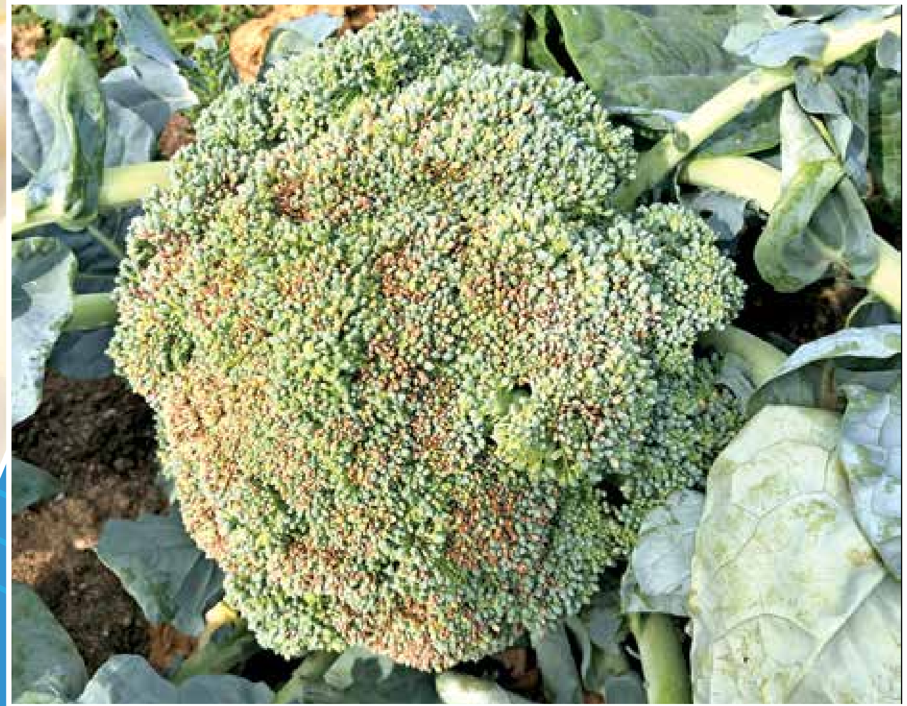
Diseases caused by *Pectobacterium* are favoured by wet weather, humid climates, excess nitrogen, poor drainage, and damage to the tissue at the base of the plant.

DISEASE MANAGEMENT

In addition to general disease management recommendations, consider hot water treatment of seed to reduce risk of primary introduction into blocks (see Appendix 3). Management of this disease requires further investigation as the effectiveness of copper and other preventative bactericides is unknown. General control of insects is recommended. Rouging infected plants at low disease incidence is likely to reduce disease spread, provided the crop debris is removed from the block and disposed of by deep burial or incineration.

There are no known resistance genes for this bacterium in brassica crops.





XANTHOMONAS CAMPESTRIS PV. CAMPESTRIS IN BRASSICAS - BLACK ROT

Black rot is only caused by *Xanthomonas campestris* pv. *campestris*, however, there are other *Xanthomonas campestris* pathovars that cause milder infection on brassica leaves only. Black rot is present in all brassica growing regions of Australia. Brassicas (cabbage, broccoli, cauliflower, leafy brassicas, and canola) and brassica weeds (mustard, wild turnip) can all be affected by this disease.

WHAT DOES IT LOOK LIKE?

Black rot symptoms are a classical yellow V-shaped lesion on the outer margin of the leaf. These lesions eventually turn papery and dry out and the tissue becomes translucent. The bacterium can move into surrounding veins causing them to blacken. Only the *Xanthomonas campestris* pv. *campestris* strain can move into the stem causing a black ring and eventual internal decay.

Other *Xanthomonas campestris* strains can cause leaf spots, resulting in a milder infection.

WHERE DOES IT COME FROM AND HOW DOES IT SPREAD?

It is a seed-borne pathogen, and can be found on the seed surface or internally from the infected mother plant.

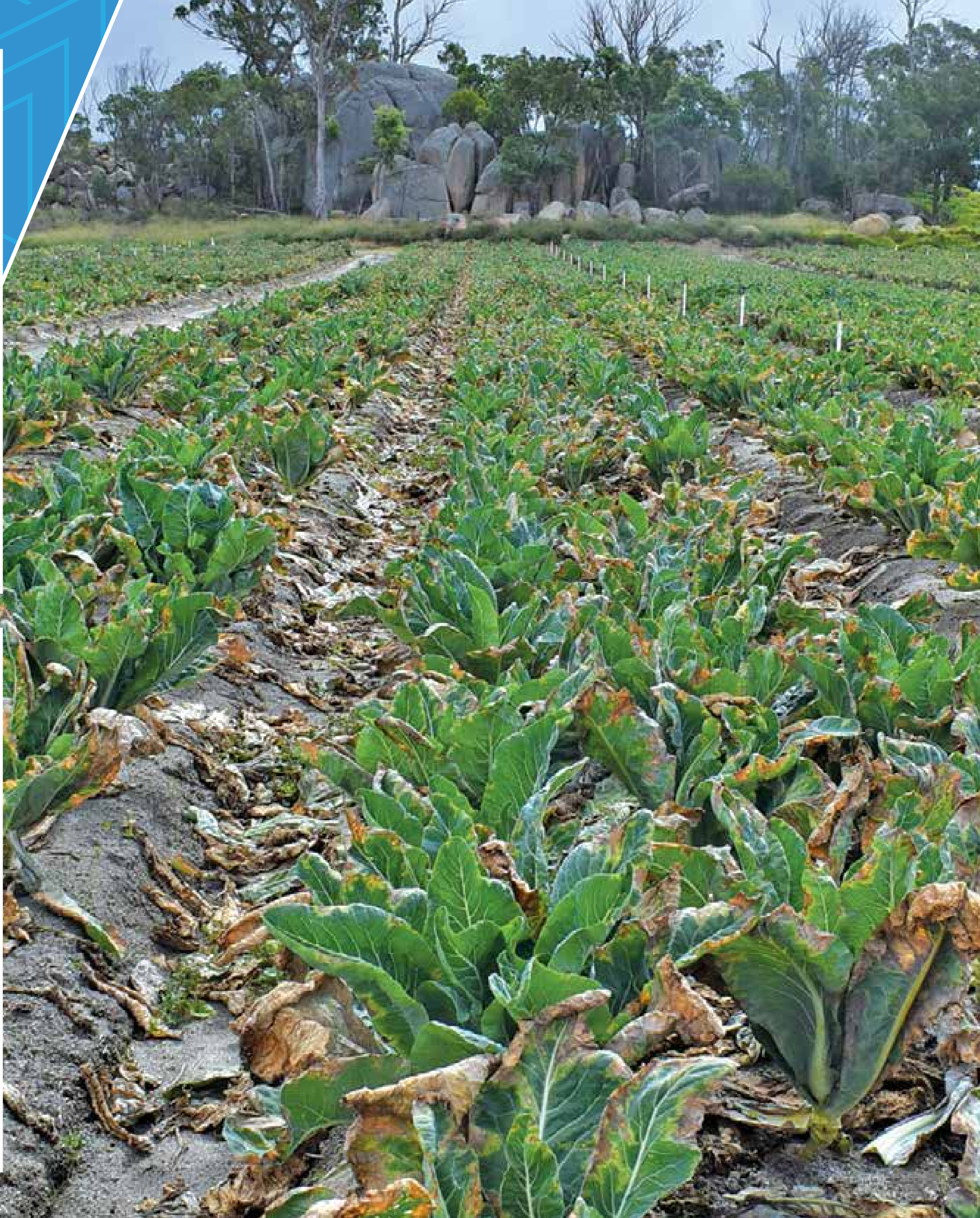
Bacterial spread in nurseries and on-farm is via water splash (rainfall or overhead irrigation), wind, and through contact spread on machinery, hand tools and people.

Spread can also occur by some insects via contact movement between infected and non-infected plants.

DISEASE MANAGEMENT

In addition to general disease management recommendations, crop management is key for reducing black rot risk and impact. Access to confirmed disease-free seedlings is a vital management tool. If you are generating your own seedlings, keep seedling production isolated from field production. The use of separate equipment and personnel in designated seedling production areas will reduce the risk of spread. Seed disinfestation using hot water treatments can be used on brassica seeds (See Appendix 3). However, there are implications for seed viability, potentially resulting in lowering of germination and establishment. This can be more pronounced with older seed that is physiologically aged.

Currently treatment options are limited for effective Black rot control. Some growers see positive effects with the use of copper, however, there are many factors that reduce efficacy including weather, application times, and disease severity. Currently there are no *X. campestris* pv. *campestris* resistant brassica varieties available.



XANTHOMONAS HORTORUM PV. VITIANS
BACTERIAL LEAF SPOT (BLS)

***Xanthomonas hortorum* pv. *vitians* infects lettuce, wild lettuce and possibly other asteraceous weed hosts, and causes bacterial leaf spot (BLS) disease.**

WHAT DOES IT LOOK LIKE?

BLS symptoms start as small, water-soaked leaf spots on the older leaves, and, as the disease progresses, these spots blacken. The spots are often limited by leaf veins giving them an angular appearance. The spots may coalesce in severe infection resulting in large black masses.

Can be confused with Septoria leaf spot which also causes angular spots, but they generally turn a pale brown and have distinct black dots which are the fungal bodies. Downy mildew also causes angular spots, but has distinct white downy fungal growth within the lesion.

WHERE DOES IT COME FROM AND HOW DOES IT SPREAD?

Xanthomonas hortorum pv. *vitians* is seed-borne, and it can be on the seed surface or internally from the infected mother plant.

Bacterial spread in nurseries and on farm is via water splash (rainfall or overhead irrigation), wind and through contact spread on machinery, hand tools and people.

Spread can also occur with some insects via contact movement between infected and non-infected plants.

DISEASE MANAGEMENT

In addition to the general disease management recommendations, crop management is key for reducing BLS risk and impact. Access to confirmed disease-free seedlings is a vital management tool. If you are generating your own seedlings keep seedling production isolated from field production. The use of separate equipment and personnel in designated seedling production areas will reduce the risk of spread.

Seed disinfestation can be used on lettuce seeds (See Appendix 3). However, there are implications on seed viability resulting in lowering of germination and establishment. This can be more pronounced with older seed that is physiologically aged.

Currently treatment options are limited for effective *Xanthomonas hortorum* pv. *vitians* control and management. Some growers see positive effects with the use of copper, however, there are many factors that reduce efficacy including weather, application times and disease severity. Currently there are no *Xanthomonas hortorum* pv. *vitians* resistant lettuce varieties available.

PSEUDOMONAS IN **VEGETABLES**

***Pseudomonas* spp. affect almost all vegetable crops and cause a range of disease symptoms. This includes spots, specks, blights, and rots. They most commonly affect lettuce, cucurbits, beans, tomato, and brassicas. A single species can also cause more than one disease in a crop depending on how and where it infects the plant.**

***Pseudomonas marginalis*, *P. cichorii* and *P. viridiflava* can also cause leaf blight, bacterial rot, and varnish spot in lettuce.**

***Pseudomonas syringae* pathovars typically cause spots or specks on plants but can also cause crown rots. They can also affect multiple crops, for example, *P. syringae* pv. *syringae* causes disease in beans, brassicas, and cucurbits.**

A list of these diseases and the crops they affect for each production district is provided in pages 30-43.

WHAT DOES IT LOOK LIKE?

Disease symptoms are varied but are typically foliar spots, specks or blights. Rots can occur with some bacteria-crop combinations, for example, lettuce and *P. cichorii*, *P. viridiflava* and *P. marginalis*.

These diseases can appear very similar to those caused by *Xanthomonas* spp. and some fungal pathogens. This includes both foliar spot diseases and plant rots. For example, lettuce rots caused by *Pseudomonas* spp. can look very similar to rots caused by fungal pathogens such as *Sclerotinia* spp. Leaf spots caused by fungi such as *Alternaria* spp. can look very similar to bacterial spots.

WHERE DOES IT COME FROM AND HOW DOES IT SPREAD?

Most *Pseudomonas* spp. are seed-borne and also ubiquitous in the environment. They survive well in soil, crop debris and water, including irrigation sources such as dams. These pathogens enter through wounds and natural openings such as hydathodes during periods of leaf wetness.

Bacterial spread in nurseries and on farm is via water splash (rainfall or overhead irrigation), wind and through contact spread on machinery, hand tools and people.

Spread can also occur with some insects via contact movement between infected and non-infected plants.

DISEASE MANAGEMENT

In addition to the general disease management, access to confirmed disease-free seedlings is a vital management tool. Seed disinfestation can be useful (see Appendix 3). If you are generating your own seedlings keep seedling production isolated from field production. The use of separate equipment and personnel in designated seedling production areas will reduce the risk of spread.

Currently treatment options are limited for effective *Pseudomonas* control management. Some growers see positive effects with the use of copper, however, there are many factors that reduce efficacy including weather, application times and disease severity. There are no known resistant hosts to *Pseudomonas* species.








PHYTOPLASMA IN **VEGETABLES**

Phytoplasma are phloem-limited bacteria that affect a wide range of crops including vegetables. The phytoplasma subgroup 16SrII-D phytoplasmas, or '*Candidatus* Phytoplasma australasia' is thought to be the major species affecting vegetable crops in Australia, although other species do occur. The disease is commonly referred to as tomato big bud or little leaf phytoplasma. This phytoplasma can affect a broad range of crops including vegetables such as bean, bitter gourd, capsicum, carrot, celery, cowpea, eggplant, lettuce, mungbean, potato, pumpkin, ridged gourd, snakebean, sweet potato, tomato and zucchini. Weeds that host phytoplasma and insect vectors play important roles in the disease cycle.

WHAT DOES IT LOOK LIKE?

Phytoplasma cause a variety of symptoms in their plant hosts and affect the development of the floral parts, leaves, roots, and/or branches. Some typical floral symptoms include the conversion of flowers into leafy tissue (phyllody), the greening of petals (virescence), and aborted fruit development. Other typical symptoms include little leaf syndrome, leaf yellowing, witches'-broom, stunting, distortion and aerial roots or tubers. Disease symptoms can sometimes be confused with physiological conditions, herbicide damage or off-type characteristics.

WHERE DOES IT COME FROM AND HOW DOES IT SPREAD?

Phytoplasma are mainly spread from one plant to the next by phloem-feeding insects such as leafhoppers, planthoppers, and psyllids where the bacteria multiply before transmission. Phytoplasmas can come into vegetable crops from environmental hosts such as weeds and native plants that may not always show any symptoms of phytoplasma infection.

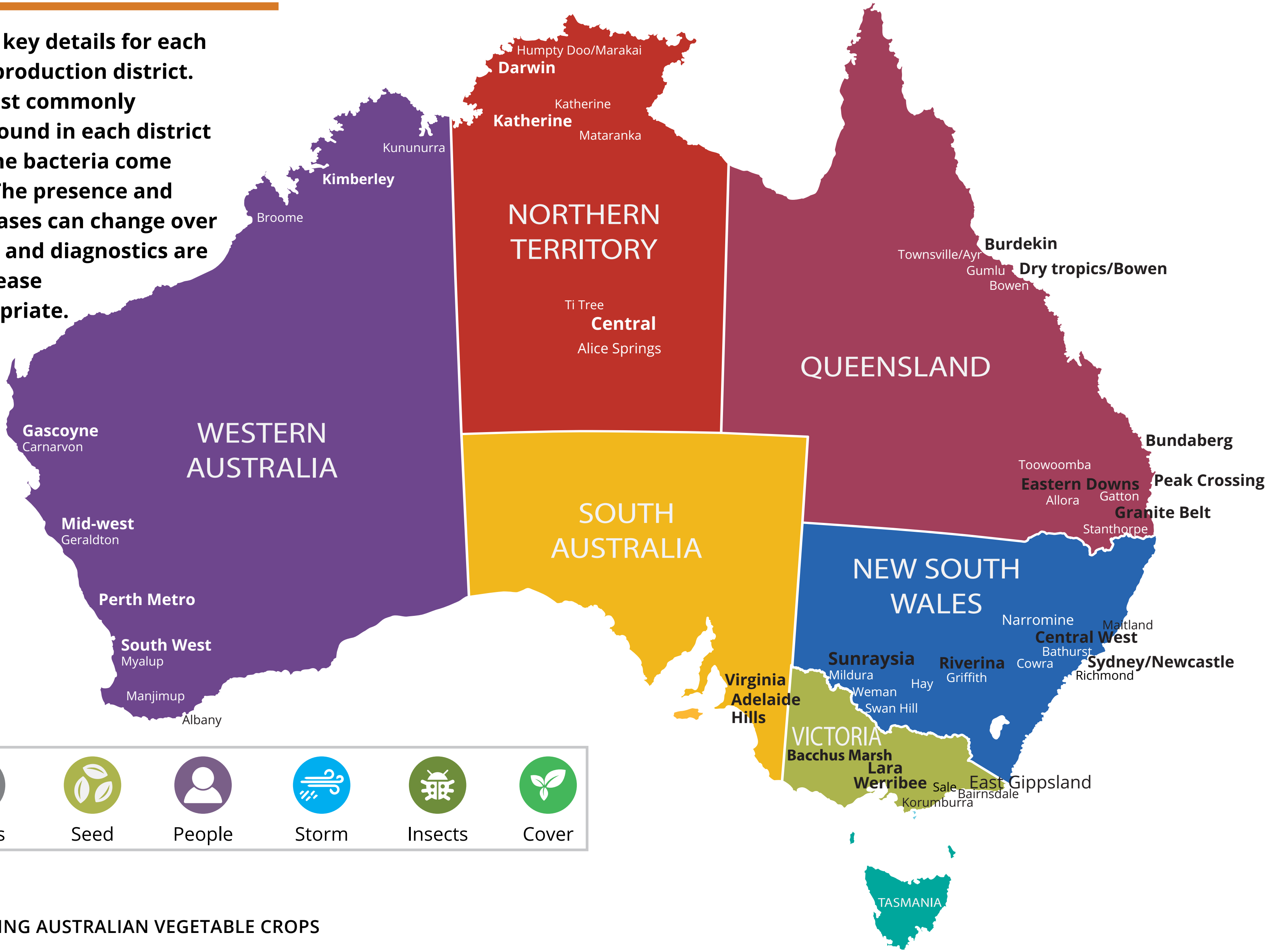
DISEASE MANAGEMENT

There are limited management strategies available to control the spread of phytoplasma diseases. Removal of infected plants and alternative weed hosts can limit phytoplasma spread to new crops by insect vectors. Use of insecticides may reduce vector migration within a crop but further movement of new vectors from surrounding vegetation can result in new infections. Netting can be effective in excluding phytoplasma vectors from areas surrounding crops and weeds, although this may not be practical. Risk of spread is low with protected cropping, where crops are completely enclosed.

There are no known management strategies for phytoplasma management. Regular monitoring of disease in crops may provide some information on seasonality to better predict disease outbreaks. Further work is needed before management strategies can be recommended.

AUSTRALIAN VEGETABLE **PRODUCTION DISTRICTS**

The following table provides key details for each major Australian vegetable production district. These details include the most commonly occurring bacterial disease found in each district and information on where the bacteria come from and how they spread. The presence and importance of bacterial diseases can change over time and regular monitoring and diagnostics are recommended to ensure disease management remains appropriate.



Queensland: Dry Tropics and Burdekin

CROP	DISEASE	BACTERIA	WHERE DOES IT COME FROM?	HOW DOES IT SPREAD IN CROP?	HOW DOES IT SPREAD TO NEW CROPS?
Capsicum, chilli	bacterial leaf spot	*Xanthomonas* species complex			
	bacterial spot	*Pseudomonas syringae*			
	soft-rot	*Pectobacterium brasiliense*			
French bean	halo Blight	*Pseudomonas syringae* pv. *phaseolicola*			
	bacterial brown spot	*Pseudomonas syringae* pv. *syringae*			
	common bacterial blight	*Xanthomonas campestris* pv. *phaseoli*			
Melons	fruit blotch	*Acidovorax citrulli*			
Pumpkin	soft rot	*Pectobacterium brasiliense*			
Tomato	bacterial spot	*Xanthomonas* species complex			
	bacterial speck	*Pseudomonas syringae* pv. *tomato*			
Zucchini	soft-rot	*Pectobacterium* spp.			
	bacterial leaf spot	*Pseudomonas syringae* pv. *syringae*			

Queensland: Lockyer Valley, Mulgowie and Lowood

CROP	DISEASE	BACTERIA	WHERE DOES IT COME FROM?	HOW DOES IT SPREAD IN CROP?	HOW DOES IT SPREAD TO NEW CROPS?
Brassicas	black rot	*Xanthomonas campestris* pv. *campestris*			
	bacterial spot	*Pseudomonas* spp.			
Capsicum, chilli	bacterial leaf spot	*Xanthomonas* species complex			
French bean	halo Blight	*Pseudomonas syringae* pv. *phaseolicola*			
	bacterial brown spot	*Pseudomonas syringae* pv. *syringae*			
	common bacterial blight	*Xanthomonas campestris* pv. *phaseoli*			
Lettuce	bacterial soft rot	*Pectobacterium carotovorum*			
	bacterial leaf spot	*Xanthomonas hortorum* pv. *vitians*			
	bacterial rots	*Pseudomonas cichorii, P. viridiflava* and *P. marginalis*			
	varnish spot	*Pseudomonas cichorii, P. viridiflava* and *P. marginalis*			
	corky root	*Rhizomonas suberifaciens*			
Pumpkin	angular leaf spot	*Pseudomonas syringae* pv. *lachrymans*			
	bacterial spot	*Xanthomonas campestris* pv. *cucurbitae*			

Tomato	tomato canker	*Clavibacter michiganensis* subsp. *michiganensis*			
	bacterial wilt	*Ralstonia solanacearum* species complex			
	bacterial leaf spot	*Xanthomonas* species complex			
	bacterial speck	*Pseudomonas syringae* pv. *tomato*			
	pith necrosis	*Pseudomonas corrugata*, *P. viridiflava*, *Pectobacterium* spp.			
Zucchini	soft-rot	*Pectobacterium* spp.			
	bacterial leaf spot	*Pseudomonas syringae*			

Queensland: Eastern downs, Clifton and Wyreema

CROP	DISEASE	BACTERIA	WHERE DOES IT COME FROM?	HOW DOES IT SPREAD IN CROP?	HOW DOES IT SPREAD TO NEW CROPS?
Brassicas	black rot	*Xanthomonas campestris* pv. *campestris*			
	bacterial spot	*Pseudomonas* spp.			
Celery	bacterial blight	*Pseudomonas syringae* pv. *apii*			
Lettuce	bacterial soft rot	*Pectobacterium carotovorum*			
	bacterial leaf spot	*Xanthomonas hortorum* pv. *vitians*			
	bacterial rots	*Pseudomonas cichorii*, *P. viridiflava* and *P. marginalis*			
	varnish spot	*Pseudomonas cichorii*, *P. viridiflava* and *P. marginalis*			
Pumpkin	angular leaf spot	*Pseudomonas syringae* pv. *lachrymans*			
	bacterial spot	*Xanthomonas campestris* pv. *cucurbitae*			

Queensland: Fassifern Valley and Peaks Crossing

CROP	DISEASE	BACTERIA	WHERE DOES IT COME FROM?	HOW DOES IT SPREAD IN CROP?	HOW DOES IT SPREAD TO NEW CROPS?
Brassicas	black rot	*Xanthomonas campestris* pv. *campestris*			
	bacterial spot	*Pseudomonas* spp.			
French bean	halo Blight	*Pseudomonas syringae* pv. *phaseolicola*			
	bacterial brown spot	*Pseudomonas syringae* pv. *syringae*			
	common bacterial blight	*Xanthomonas campestris* pv. *phaseoli*			
Lettuce	bacterial soft rot	*Pectobacterium carotovorum*			
	bacterial leaf spot	*Xanthomonas hortorum* pv. *vitians*			
	bacterial rots	*Pseudomonas cichorii, P. viridiflava* and *P. marginalis*			
	varnish spot	*Pseudomonas cichorii, P. viridiflava* and *P. marginalis*			
Pumpkin	angular leaf spot	*Pseudomonas syringae* pv. *lachrymans*			
	bacterial spot	*Xanthomonas campestris* pv. *cucurbitae*			

Queensland: Granite Belt

CROP	DISEASE	BACTERIA	WHERE DOES IT COME FROM?	HOW DOES IT SPREAD IN CROP?	HOW DOES IT SPREAD TO NEW CROPS?
Brassicas	black rot	*Xanthomonas campestris* pv. *campestris*			
	bacterial spot	*Pseudomonas* spp.			
	bacterial soft rot	*Pectobacterium* spp.			

Capsicum, chilli	bacterial leaf spot	*Xanthomonas* species complex			
	tomato canker	*Clavibacter michiganensis* subsp. *michiganensis*			
Celery	bacterial blight	*Pseudomonas syringae* pv. *apii*			
French bean	halo Blight	*Pseudomonas syringae* pv. *phaseolicola*			
	bacterial brown spot	*Pseudomonas syringae* pv. *syringae*			
	common bacterial blight	*Xanthomonas campestris* pv. *phaseoli*			
Parsley	bacterial leaf spot	*Pseudomonas syringae*			
	bacterial shoot blight	*Pseudomonas* spp.			
Tomato	bacterial spot	*Xanthomonas* species complex			
	bacterial speck	*Pseudomonas syringae* pv. *tomato*			
	tomato canker	*Clavibacter michiganensis* subsp. *michiganensis*			
	bacterial wilt	*Ralstonia solanacearum* species complex			
Zucchini	soft-rot	*Pectobacterium* spp.			
	angular leaf spot	*Pseudomonas syringae* pv. *lachrymans*			

NSW: Sydney to Newcastle (Sydney Basin, Newcastle, Maitland, Gosford, Peats Ridge)

CROP	DISEASE	BACTERIA	WHERE DOES IT COME FROM?	HOW DOES IT SPREAD IN CROP?	HOW DOES IT SPREAD TO NEW CROPS?
Beets	leaf spot, leaf blight	*Pseudomonas syringae* pv. *aptata*			
Brassicas	soft rot	*Pectobacterium carotovorum*			
	black rot	*Xanthomonas campestris* pv. *campestris*			
Lettuce	bacterial leaf spot	*Xanthomonas hortorum* pv. *vitians*			
	bacterial rots	*Pseudomonas marginalis*, *Pseudomonas viridiflava*			
	varnish spot	*Pseudomonas cichorii*			

NSW: Central West (Bathurst, Cowra and Narromine)

CROP	DISEASE	BACTERIA	WHERE DOES IT COME FROM?	HOW DOES IT SPREAD IN CROP?	HOW DOES IT SPREAD TO NEW CROPS?
Beets	leaf spot, leaf blight	*Pseudomonas syringae*			
Brassicas	black rot	*Xanthomonas campestris* pv. *campestris*			
	leaf spot	*Pseudomonas syringae* pv. *maculicola*			

NSW: Riverina (Griffith and Hay)

CROP	DISEASE	BACTERIA	WHERE DOES IT COME FROM?	HOW DOES IT SPREAD IN CROP?	HOW DOES IT SPREAD TO NEW CROPS?
Brassicas	black rot	*Xanthomonas campestris* pv. *campestris*			

Victoria: Bacchus Marsh

CROP	DISEASE	BACTERIA	WHERE DOES IT COME FROM?	HOW DOES IT SPREAD IN CROP?	HOW DOES IT SPREAD TO NEW CROPS?
Brassicas	black rot	*Xanthomonas campestris* pv. *campestris*			

Victoria: Gippsland

CROP	DISEASE	BACTERIA	WHERE DOES IT COME FROM?	HOW DOES IT SPREAD IN CROP?	HOW DOES IT SPREAD TO NEW CROPS?
Brassicas	black rot	*Xanthomonas campestris* pv. *campestris*			
	bacterial speck	*Pseudomonas syringae* pv. *tomato*			
	bacterial leaf spot	*Pseudomonas viridiflava*			
	bacterial leaf spot	*Xanthomonas* spp.			
Chard	bacterial leaf spot	*Pseudomonas syringae* pv. *syringae*			
French bean	halo Blight	*Pseudomonas syringae* pv. *phaseolicola*			
	bacterial brown spot	*Pseudomonas syringae* pv. *syringae*			
Lettuce	varnish spot	*Pseudomonas viridiflava*			
	bacterial leaf spot	*Xanthomonas hortorum* pv. *vitians*			
Tomato	tomato canker	*Clavibacter michiganensis* subsp. *michiganensis*			

Victoria: S.E. Melbourne

CROP	DISEASE	BACTERIA	WHERE DOES IT COME FROM?	HOW DOES IT SPREAD IN CROP?	HOW DOES IT SPREAD TO NEW CROPS?
Coriander	bacterial blight	*Pseudomonas viridiflava*			
Lettuce	vanish spot	*Pseudomonas cichorii*			
Brassicas	bacterial leaf spot	*Pseudomonas viridiflava*			

Victoria: Werribee

CROP	DISEASE	BACTERIA	WHERE DOES IT COME FROM?	HOW DOES IT SPREAD IN CROP?	HOW DOES IT SPREAD TO NEW CROPS?
Brassicas	black rot	*Xanthomonas campestris* pv. *campestris*			
Lettuce	varnish spot	*Pseudomonas cichorii* and *P. viridiflava*			
	corky root	*Rhizorhapis suberifaciens*			
Tomato	pith necrosis	*Pseudomonas corrugata*			
	tomato canker	*Clavibacter michiganensis* subsp. *michiganensis*			

South Australia: Virginia and Adelaide Hills

CROP	DISEASE	BACTERIA	WHERE DOES IT COME FROM?	HOW DOES IT SPREAD IN CROP?	HOW DOES IT SPREAD TO NEW CROPS?
Brassicas	bacterial leaf spot	*Pseudomonas viridiflava*			
Tomato	bacterial speck	*Pseudomonas syringae* pv. *tomato*			
	tomato canker	*Clavibacter michiganensis* subsp. *michiganensis*			

Western Australia: Gascoyne: Carnarvon

CROP	DISEASE	BACTERIA	WHERE DOES IT COME FROM?	HOW DOES IT SPREAD IN CROP?	HOW DOES IT SPREAD TO NEW CROPS?
Capsicum, chilli	leaf spot	*Pseudomonas* spp.			
French bean	halo Blight	*Pseudomonas syringae* pv. *phaseolicola*			
	bacterial brown spot	*Pseudomonas syringae* pv. *syringae*			
	common bacterial blight	*Xanthomonas campestris* pv. *phaseoli*			
Pumpkin	soft rot (crown)	*Pectobacterium carotovorum*			
Tomato	bacterial speck	*Pseudomonas* spp.			
	tomato canker	*Clavibacter michiganensis* subsp. *michiganensis*			
Zucchini	soft rot (crown)	*Pectobacterium carotovorum*			

Western Australia: Mid western: Geraldton

CROP	DISEASE	BACTERIA	WHERE DOES IT COME FROM?	HOW DOES IT SPREAD IN CROP?	HOW DOES IT SPREAD TO NEW CROPS?
Capsicum, chilli	leaf spot	*Pseudomonas* spp.			
Tomato	bacterial speck	*Pseudomonas* spp.			
	tomato canker	*Clavibacter michiganensis* subsp. *michiganensis*			

Western Australia: Perth: Wanneroo, Gingin, Carabooda

CROP	DISEASE	BACTERIA	WHERE DOES IT COME FROM?	HOW DOES IT SPREAD IN CROP?	HOW DOES IT SPREAD TO NEW CROPS?
Capsicum, chilli	leaf spot	*Pseudomonas* spp.			
Gai Lan	bacterial spot	*Pseudomonas syringae*			
Ipomea aquatica		*Xanthomonas campestris*			
Tomato	bacterial speck	*Pseudomonas syringae*			
	tomato canker	*Clavibacter michiganensis* subsp. *michiganensis*			

Western Australia: South West – Myalup, Manjimup, Albany

CROP	DISEASE	BACTERIA	WHERE DOES IT COME FROM?	HOW DOES IT SPREAD IN CROP?	HOW DOES IT SPREAD TO NEW CROPS?
Brassicas	black rot	*Xanthomonas campestris* pv. *campestris*			
	soft rot	*Pectobacterium carotovorum*			
Celery	bacterial leaf spot	*Pseudomonas* spp.			
Fennel	soft rot	*Pectobacterium carotovorum*			
Tomato	soft rot	*Pantoea agglomerans*			

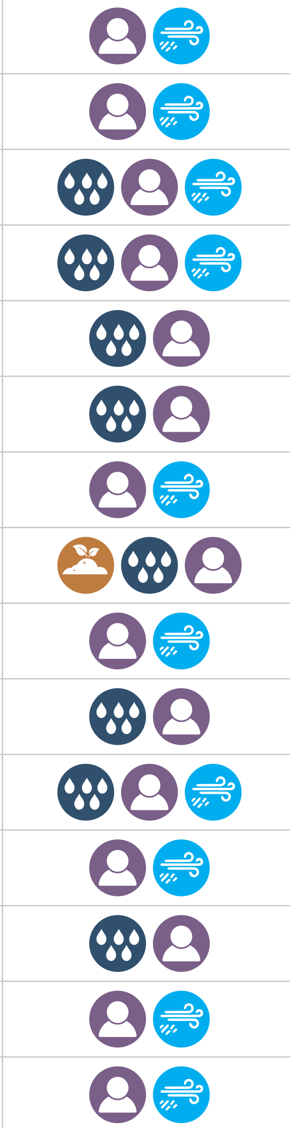
Northern Territory: Darwin Region

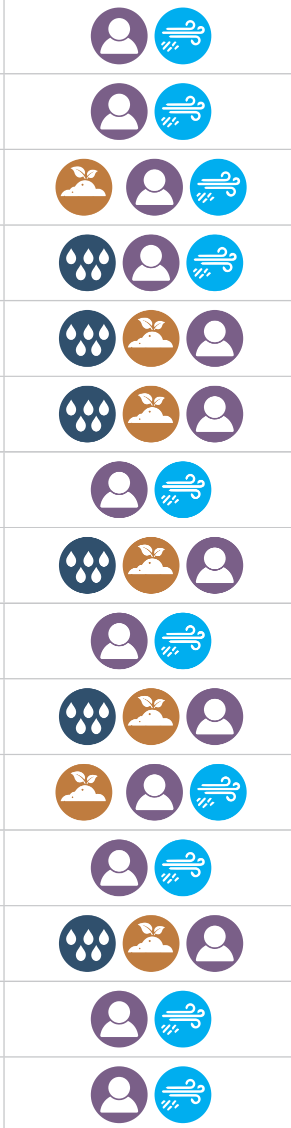
CROP	DISEASE	BACTERIA	WHERE DOES IT COME FROM?	HOW DOES IT SPREAD IN CROP?	HOW DOES IT SPREAD TO NEW CROPS?
Asian melons[1]	bacterial leaf spot	*Xanthomonas* spp.			
Capsicum, chilli	bacterial leaf spot	*Xanthomonas* species complex			
	bacterial leaf spot	*Pseudomonas* spp.			
	soft rot	*Pantoea* spp.			
	bacterial wilt	*Ralstonia solanacearum* species complex			
Cucumber	bacterial leaf spot	*Pseudomonas* spp.			
	bacterial leaf spot	*Xanthomonas* spp.			
Eggplant	bacterial wilt	*Ralstonia solanacearum* species complex			
Mung bean	bacterial wilt	*Curtobacterium flaccumfaciens* pv. *flaccumfaciens*			
	bacterial leaf spot	*Xanthomonas* spp.			
Peanut	bacterial wilt	*Ralstonia solanacearum* species complex			
Snake bean	bacterial wilt	*Curtobacterium flaccumfaciens* pv. *flaccumfaciens*			
Soy bean	bacterial leaf spot	*Xanthomonas campestris*			
	bacterial leaf spot	*Pseudomonas* spp.			
Tomato	bacterial wilt	*Ralstonia solanacearum* species complex			
	bacterial leaf spot	*Xanthomonas* spp.			
Watermelon	bacterial leaf spot	*Xanthomonas* spp.			

1 including bitter melon, long melon, snake gourd, luffa, sinqua etc.

Northern Territory: Katherine Region

CROP	DISEASE	BACTERIA	WHERE DOES IT COME FROM?	HOW DOES IT SPREAD IN CROP?	HOW DOES IT SPREAD TO NEW CROPS?
Brassicas	bacterial leaf spot	*Xanthomonas campestris*			
Capsicum, chilli	bacterial leaf spot	*Xanthomonas* spp.			
	bacterial leaf spot	*Pseudomonas* spp.			
	soft rot	*Pantoea* spp.			
	bacterial wilt	*Ralstonia solanacearum* species complex			
Eggplant	bacterial wilt	*Ralstonia solanacearum* species complex			
Lettuce	bacterial leaf spot	*Xanthomonas hortorum* pv. *vitians*			
Mung bean	bacterial wilt	*Curtobacterium flaccumfaciens* pv. *flaccumfaciens*			
	bacterial leaf spot	*Xanthomonas campestris*			
Peanut	bacterial wilt	*Ralstonia solanacearum* species complex			
	bacterial leaf spot	*Pseudomonas* spp.			
Soy bean	bacterial leaf spot	*Xanthomonas campestris*			
Tomato	bacterial wilt	*Ralstonia solanacearum* species complex			
	bacterial leaf spot	*Xanthomonas* spp.			
Watermelon	bacterial leaf spot	*Xanthomonas* spp.			





APPENDIX 1
DIAGNOSTIC SERVICES

Institute	Laboratory	Weblink
DAF, QLD	Grow Help Australia	https://www.business.qld.gov.au/industries/farms-fishing-forestry/agriculture/agribusiness/grow-help-australia/service
DJPR, VIC	Crop Health Services	https://agriculture.vic.gov.au/support-and-resources/services/diagnostic-services
DPRIR, NT	Berrimah Agricultural Lab	https://industry.nt.gov.au/contacts/laboratories
DPIRD, WA	DPIRD Diagnostic Laboratory Services	https://www.agric.wa.gov.au/livestock-biosecurity/dpird-diagnostics-and-laboratory-services-ddls-animal-pathology
DPI, NSW	Elizabeth Macarthur Agricultural Institute	https://www.dpi.nsw.gov.au/about-us/science-and-research/centres/emai
DPIPWE, TAS	Plant Diagnostic Service	https://nre.tas.gov.au/biosecurity-tasmania/plant-biosecurity/plant-diagnostic-services

APPENDIX 2
SAMPLE COLLECTION AND PACKAGING

When attempting to identify bacterial diseases, correctly sampling the tissue and packing the sample is crucial. Smaller lesions near healthy tissue are ideal, whereas old, rotten lesions are more likely to contain other organisms that exist in the environment and will complicate diagnostic results. The following section is a general guide to packaging samples for bacterial identification, however, there are packaging guides specific to various crops/ sample types and diseases available on the above diagnostic services' websites.

When deciding what part of the plant needs to be sent, it is helpful to include more tissue than not enough. For example, if the suspect symptom is a leaf spot, try to send a range of representative spots, as well as some healthy leaves for comparison. Also include some petiole/ stem in case the pathogen is systemic and more easily isolated from these plant parts. For wilt symptoms, the whole plant is needed to find out if the problem is in the roots or stem. If you are unsure, sending the whole plant allows for the best chance of identifying the problem. Preferably send the root system in a separate bag to the remainder of the plant to reduce contamination of leaves and stem with dirt. Put samples in a paper bag inside a plastic bag or in a plastic bag with a small amount of paper. This is to avoid condensation inside plastic bags to keep the samples relatively dry.

APPENDIX 3
HOW DOES COPPER PROTECT PLANTS FROM BACTERIAL INFECTIONS?

Evolution of copper tolerance in bacterial populations means they can tolerate higher concentrations of copper than sensitive ones but not that they are resistant to copper. Copper tolerance partly explains why copper is not effective to control bacterial diseases, however, even copper sensitive bacteria are difficult to manage with copper. The key to control of bacteria with copper is the availability of free cupric ions (Cu^{2+}). How much Cu^{2+} is available after application is very difficult to estimate.

Products with a Cu^{2+} concentration of 1.5 µg/ml or more are most effective for control, however, commercial products can range from 0.04 to 22.0 µg/ml Cu^{2+} and it's not listed on the label. There is no direct link between total copper applied and available Cu^{2+}. The available Cu^{2+} on a plant depends on the equilibrium between the complexed and soluble forms of copper and the chemical reactions releasing the free Cu^{2+} from the soluble forms. Free Cu^{2+} typically increases with increased amounts of soluble copper, however, the amount of free Cu^{2+} present on plant surfaces is only a small fraction of the soluble copper present. For example, in studies on bean, free Cu^{2+} was estimated to be as low as 1% of the soluble copper present.

The half-life of copper on a plant is generally about one month. Extra applications above the recommended 7 to 10 days don't improve Cu^{2+} availability. However, extra applications should be considered if heavy rainfall has occurred, as this will physically remove copper, and to protect new foliage for fast growing crops. Application techniques and product type affect coverage of the plants with copper and this also influences the efficacy of copper as a bactericide.

WHAT COPPER PRODUCTS ARE USED IN VEGETABLES CROPS?

Products registered for use against bacterial diseases include Bordeaux mixture, cupric and cuprous hydroxide, cuprous oxide, copper oxychloride, copper salts of fatty acids, copper ammonia acetate complexes, tribasic copper sulphate and mixtures of cupric hydroxide and ethylene bis-dithiocarbamates (EBDC, e.g. mancozeb).

Tank mixes including fungicides such as EBDC (e.g. mancozeb) or heavy metals including zinc or iron will improve disease control by increasing the amount of Cu^{2+} in solution. On the other hand, mixing copper products with organic compounds is highly likely to have the reverse effect and reduce availability of Cu^{2+}.

Copper plus EBDC is consistently better than copper only products in field studies of a range of bacterial diseases, including bacterial spot and speck of tomato. This is attributed to the ability of the bis-dithiocarbamate anion to chelate copper and transport the Cu^{2+} into the bacteria. As stated above it also improves the concentration of Cu^{2+} in solution.

Ferric chloride combined with cupric hydroxide improved bacterial disease control in walnut. The ferric chloride increased the sensitivity of the bacterium to the copper. It also increased

availability of Cu^{2+} on plants by lowering the pH and cation exchange between Cu^{2+} and Fe^{3+}. However, lowering the pH with hydrochloric acid or adding a range of other metal ions ($MnSO_4$, $MgCl_2$, $MgSO_4$, $CaCl_2$, NaCl and KCl) did not increase availability of Cu^{2+}. Although zinc used instead of, or in combination with, copper is effective in disease control in walnut, further work is needed as again different combinations of product give very different results. Specific research in vegetable crops is also needed.

SUGGESTED SPRAY PROGRAM

What can be mixed with what in the spray tank?

A tank mix of copper plus an EBDC (ethylene bis-dithiocarbamates, e.g. mancozeb) will give the best disease control compared to copper alone. Additionally, avoid mixing the copper with other products that will complex the copper reducing its solubility and ultimately the availability of Cu^{2+}.

Some biological control agents are registered for use as bactericides in vegetables and can be mixed with copper.

Are some formulations better than others?

There are various forms of copper registered for use. These include Bordeaux mixture, cupric and cuprous hydroxide, copper salts of fatty acids, copper ammonia acetate complexes, tribasic copper sulphate and mixtures of cupric hydroxide and ethylene bis-dithiocarbamates (EBDC). There are no strict rules as to which form of copper works best.

Products come as wettable powders, wettable granules, liquid flowable suspensions or aqueous liquids. The formulation will affect coverage of the product which is an important factor to consider. It may also affect solubility of the copper and availability of Cu^{2+}. Additivities to products could also potentially affect solubility and/or Cu^{2+} availability. Consult your local supplier for more information about the solubility and Cu^{2+} availability of specific products.

New copper formulations are under study for use in vegetable crops. These products have improved chemistries and are likely to provide better protection against bacterial infections. Regular review of available products through APVMA or talking to your local chemical supplier is recommended to remain up to date with available products and their efficacy.

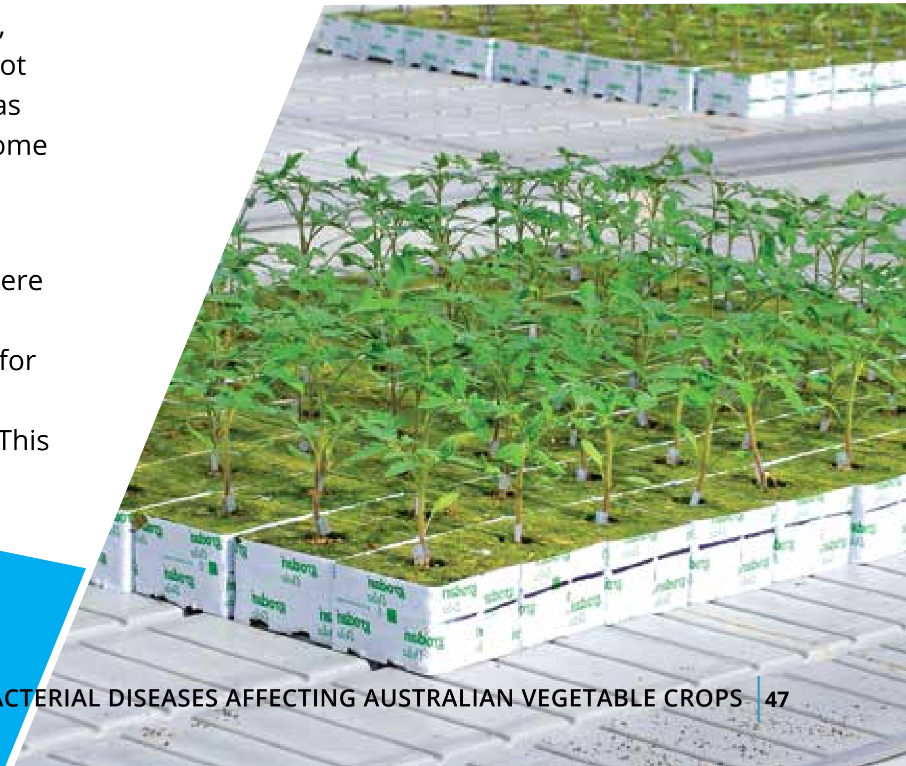
APPENDIX 4
IS SEED DISINFESTATION TREATMENT USEFUL?

The disinfestation treatment of seed to reduce risk of introduction of pathogens into commercial crops is a feasible option for some vegetable crops. Many bacteria affecting vegetable crops are seed-borne and linkages with field disease outbreaks are often reported. Ongoing high-volume international trade in seed, together with the high seed-transmissibility of some of these bacteria, also increases the risk of co-importation of new races or species into Australia. Seed disinfestation helps mitigate both local disease outbreaks each season and introduction of new diseases. General seed disinfestation treatments such as hot water has the added benefit of eliminating other plant pathogens including some viruses and fungi (see following table).

Incubation of seed in hot water is a very common, highly effective, method for seed disinfestation and should be done close to sowing as storage after treatment affects germination rates. The method used will depend on the plant species as seed size influences efficacy of the treatment.

A general treatment at 50 - 53°C for 10-30 min has good effect but at 40°C there is no significant reduction of seed-borne pathogens, even with longer incubation times. Hot water treatment is recommended for small-seeded crops such as capsicum, eggplant, tomato, cucumber, carrot, spinach, lettuce, celery, cabbage, turnip, and brassicas but may not be practical for large-seeded crops such as peas, beans, sweet corn, beetroot, and some cucurbits.

An exception to the temperature recommendation is for brassica seed, where a combination of lower temperature and cupric acetate was shown to be effective for seed disinfestation to eliminate black rot (*Xanthomonas campestris* pv. *campestris*). This method involves incubating seed in a pre-warmed 0.2% (w/v) cupric acetate with 0.1% (v/v) glacial acetic acid and 0.02% (v/v) Triton X-100 solution at 40°C for 20 min with gentle shaking. Seed are treated at a rate of 40g seed to 400ml of treatment solution. Seed are rinsed twice in water and then dried.



Seed disinfestation protocols for different vegetable crops recommended by the University of Massachusetts Amherst (UMass 2015).

Crop	Temperature (°C)	Time (min)	Diseases and pathogens removed from seed
Brassicas	50	20-25	bacterial leaf spots (*Pseudomonas syringae* pv. *maculicola* and *Xanthomonas campestris* pv. *raphani*), black leg (aka phoma stem canker, *Phoma lingam*), alternaria disease (black spot, gray leaf spot and pod spot, *Alternaria brassicicola* and *A. japonica*) and *Alfalfa mosaic virus*.
Capsicum	52	30	BLS (*Xanthomonas* species complex), anthracnose (*Colletotrichum* spp.), *Cucumber mosaic virus, Pepper mild mosaic virus*, *Tobacco* and *Tomato mosaic virus*
Carrot	50	20	alternaria leaf blight (*Alternaria dauci*), bacterial leaf blight (*Xanthomonas campestris* pv. *carotae*), cercospora leaf spot (*Cercospora carotae*), crater rot (*Athelia arachnoidea* aka *Rhizoctonia carotae*) and southern foliar blight (*A. rolfsii* aka *Sclerotium rolfsii*).
Celery/ Celeriac	48	30	bacterial leaf spot (*Pseudomonas syringae* pv. *apii*), cercospora leaf spot (*Cercospora apii*), septoria leaf spot (aka late blight, *Septoria apiicola*), phoma crown and root rot (*Phoma apiicola*)
Eggplant	50	25	anthracnose, early blight, phomopsis, verticillium wilt
Lettuce	48	30	anthracnose (*Microdochium panattonianum*), bacterial leaf spot (*Xanthomonas campestris* pv. *vitians*), *lettuce mosaic virus*, septoria leaf spot (*Septoria lactucae* and *S. birgitae*), verticillium wilt (*Verticillium dahliae*)
Onion	50	20	purple blotch (*Alternaria porri*), stemphylium leaf blight (*Stemphylium vesicarium*), basal rot (*Fusarium culmorum*, *F. oxysporum* f.sp. *cepae* and *F. proliferatum*), botrytis blight (*Botrytis squamosa*), smudge (*Colletotrichum circinans*), black mould (*Aspergillus niger*), downy mildew *Peronospora desctructor*), bacterial blight (*Pseudomonas syringae* pv. *porri*)
Parsley	50	30	bacterial leaf spot (*Pseudomonas syringae* pv. *apii*), alternaria leaf blight (*Alternaria petroselini*, *A. selini* and *A. smyrnii*), black rot, cercospora leaf spot (*Cercospora apii*), and septoria leaf spot (aka late blight, *Septoria apiicola*),
Spinach	50	25	anthracnose (*Collectotrichum dematium* f.sp *spinaciae*), cladosporium leaf spot (*Cladosporium variabile*), *cucumber mosaic virus*, downy mildew (*Peronospora farinosa* f.sp *spinaciae*), fusarium wilt (*Fusarium oxysporum* f.sp. *spinaciae*), stemphylium leaf spot (*Stemphylium botryosum*), and verticillium wilt (*Verticillium dahliae*)
Tomato	50	25	BLS (*Xanthomonas* species complex), *alfalfa mosaic virus*, anthracnose (*Colletotrichum* spp.), bacterial canker (*Clavibacter michiganensis* subsp. *michiganensis*), bacterial speck (*Pseudomonas syringae* pv. *tomato*), bacterial wilt (*Ralstonia solanacearum*), *cucumber mosaic virus*, early blight (*Alternaria solani*), fusarium wilt (*Fusarium oxysporum* fsp. *lycopersici*), leaf mold (*Passalora fulva*), septoria leaf spot (*Septoria lycopersici*), *tomato mosaic virus* and verticillium wilt (*Verticillium albo-atrum* and *Verticillium dahliae*).

APPENDIX 4
IS SEED DISINFESTATION TREATMENT USEFUL? CONTINUED

For watermelon seed, a specific hot water treatment was developed in Australia to eliminate bacterial fruit blotch (*Acidovorax avenae* subsp. *citrulli*). The method involves incubation of the seed at 55°C for 20 min.

After treatment seed are immediately cooled in room temperature water, dried and sown within 48h. This method is also likely to work with other cucurbit crops including zucchini, pumpkin, other melons and cucumber, although temperatures and times may need changing to optimise germination rates.

In addition to bacterial fruit blotch, this method also eliminates bacterial leaf spot and angular leaf spot (*Xanthomonas curcurbitae*, *Pseudomonas syringae* pv. *syringae* and *P. syringae* pv. *lachrymans*), fusarium crown and foot rot (*Fusarium solani f.sp. cucurbitae*), fusarium wilt, root and stem rot (*F. oxysporum f.sp. cucumerinum*, *f.sp melonis*, *f.sp niveum* and *f.sp radicis-cucumerinum*), anthracnose (*Colletotrichum orbiculare*) and gummy stem blight and black rot (*Stagonosporopsis* spp.).

For other vegetable crops, disinfestation methods will need to be developed and validated.

When deciding if heat treatment of seed is needed consider the following questions?

- What disease are you trying to control and is seed contamination a significant risk?
- Was the seed produced in a way that was likely to minimise the potential for it to become contaminated?
- Was the seed tested by the supplier?
- Has the seed already been heat or otherwise treated?

The tables of common diseases lists which bacteria are seed-borne (see pages 30-43). To assist with answering the remaining questions talk to your local seed company and nursery supplier.

Also consider if the seed is coated with fungicide or insecticide as these coatings will be removed during the process. If you need this protection, hot water treatment might not be feasible or you may need to reapply the products.

If you haven't tried hot water treatment before, it is recommended to start with small batches of seed to optimise the method, checking germination rates as you go, before doing large batches. Also, hot water treated seed will not store for very long so only treat in batches which are to be sown within 48h of treatment.

GLOSSARY OF TERMS

abiotic	physical rather than biological
bacteria	single-celled organism
chemotaxis	the directed movement of a cell in response to a chemical stimulus
coalesce	merge together to form a larger mass
disinfestation	physical or chemical process to destroy or remove undesirable entities
disorder	interruption of normal function
forma specialis (f.sp.)	a taxonomic group within a pathogen species (usually fungal) defined in terms of host range
hydathode	a modified pore, especially on a leaf, which exudes drops of water
lesion	a localised area of diseased tissue
obligate pathogen	an organism that cannot survive outside its host
pathovar (pv.)	a subspecies or group of strains that can infect a limited range of plants species
phloem	the vascular tissue in plants which conducts sugars and other metabolic products downwards from the leaves.
phyllody	abnormal development of floral parts into leafy structures
plant pathogen	a bacteria, virus, fungi or nematode species able to cause disease in a plant
race/strain/biovar	a genetically or geographically distinct group within a species, or a group of pathogens that infect a given set of plant varieties
solanaceae (solanaceous)	plants in the nightshade family; tomato, capsicum, chilli, eggplant and potato
species (sp.)	a taxonomic group within a family defined by similar characteristics
subspecies (subsp.)	a group within a species that has become somewhat physically and genetically different from the rest of the species
vascular tissue	is the internal plant stem tissue comprised of the xylem and the phloem, the main transport systems of plants
virescence	abnormal development of green pigmentation in plant parts that are not normally green like flowers
xylem	the vascular tissue in plants which conducts water and dissolved nutrients upwards from the root