INTEGRATED DISEASE MANAGEMENT FOR FOLIAR AND FRUIT DISEASES OF CITRUS

Best Management Practices

Hort Innovation CITRUS FUND

Queensland Government

Acknowledgements

Queensland Department of Primary Industries gratefully acknowledges the financial support of Hort Innovation, using the citrus R&D levy and contributions from the Australian Government, and the Queensland citrus industry. Without this support, the project CT20009 - Integrated disease management of Citrus Black Spot and 'Emperor' Brown Spot, within which these guidelines were generated, would not have been conducted.

The knowledge generated in a previous Hort Innovation funded project, CT13021 - Joint Florida and Australian Citrus Black Spot Research Initiative, is also acknowledged, again making it possible to significantly further an understanding of Citrus Black Spot management in citrus in sub-tropical climates within the timelines of CT20009.

This document seeks to address the principals of Integrated Disease Management and to provide information regarding IDM of the foliar and fruit diseases that affect citrus production in the sub-tropics and tropics. There are several recently published sources of information that have a similar but wider remit (diseases, pests, temperate production regions) and their details are provided in the Useful Resources section. This document was requested by the Queensland industry.

Contents

What is IDM?

Integrated disease management (IDM) is a system that seeks to provide a balanced mechanism of disease control by using a variety of management tools. This means adopting cultural and biological control measures alongside more conscious chemical usage (Figure 1).

The aim is successful disease management using reduced pesticide inputs while building a natural environment that promotes biodiversity and a degree of self-sustaining plant health. If used effectively, cultural and biological control methods can provide excellent disease control and significantly decrease chemical usage.

One immediately quantifiable benefit of IDM is reduced input costs (e.g. fungicide costs), while others include reducing the risk of building or elevated preparedness for fungicide loss (deregistration) or major usage pattern changes. For example, at the time of writing this document, mancozeb, a dithiocarbonate fungicide used frequently in the citrus industry, is slated for review in Australia in 2027 and its loss would require immediate implementation of alternative disease management measures in citrus and many other crops.

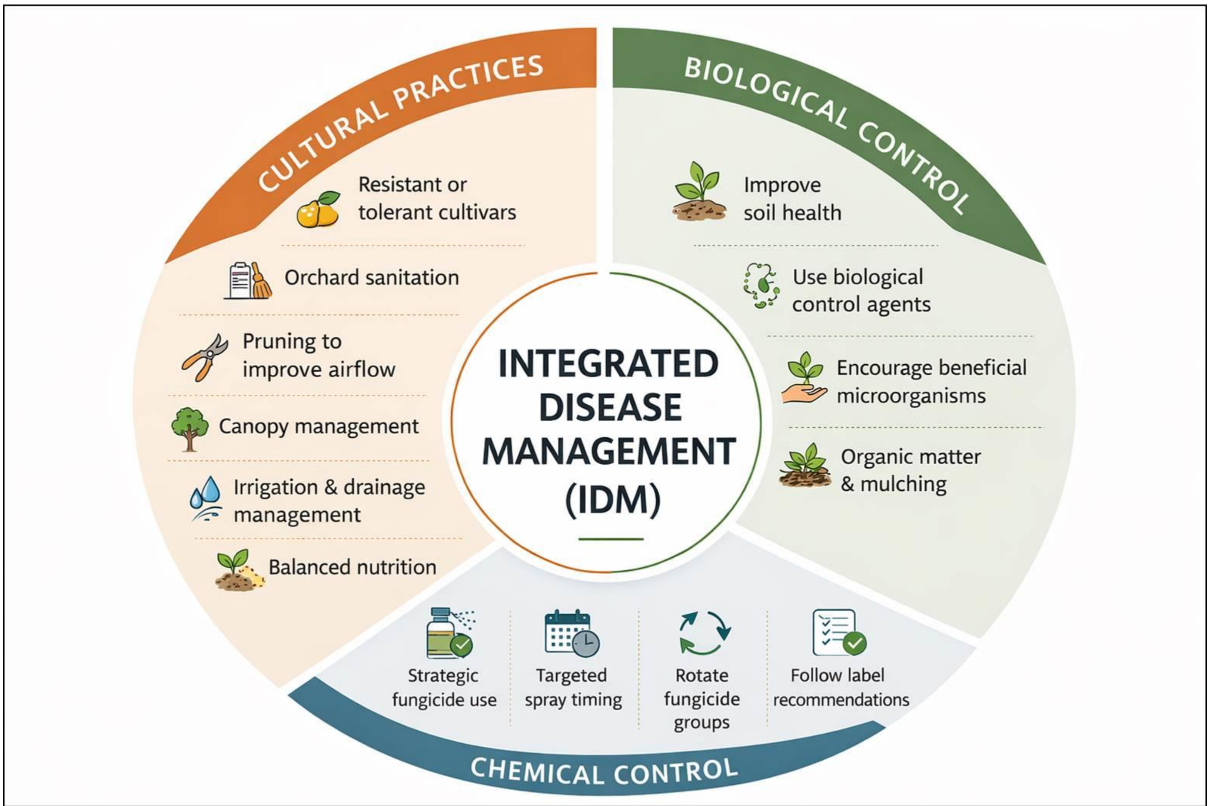

Figure 1: Principles of Integrated Disease Management (Image credit: T. Thangavel).

Understanding how diseases develop is helpful to implementing IDM in a practical and successful way. The three key requirements for a disease to establish and spread are 1) the presence of a susceptible host, 2) conducive environmental conditions (including soil conditions) and 3) presence of the pathogen.

This is known as the disease triangle (Figure 2) and each component of the triangle needs to be fulfilled for disease to occur or to be severe. On the surface it seems intuitive, but each component needs to be understood for an individual farm, local environment and climatic region.

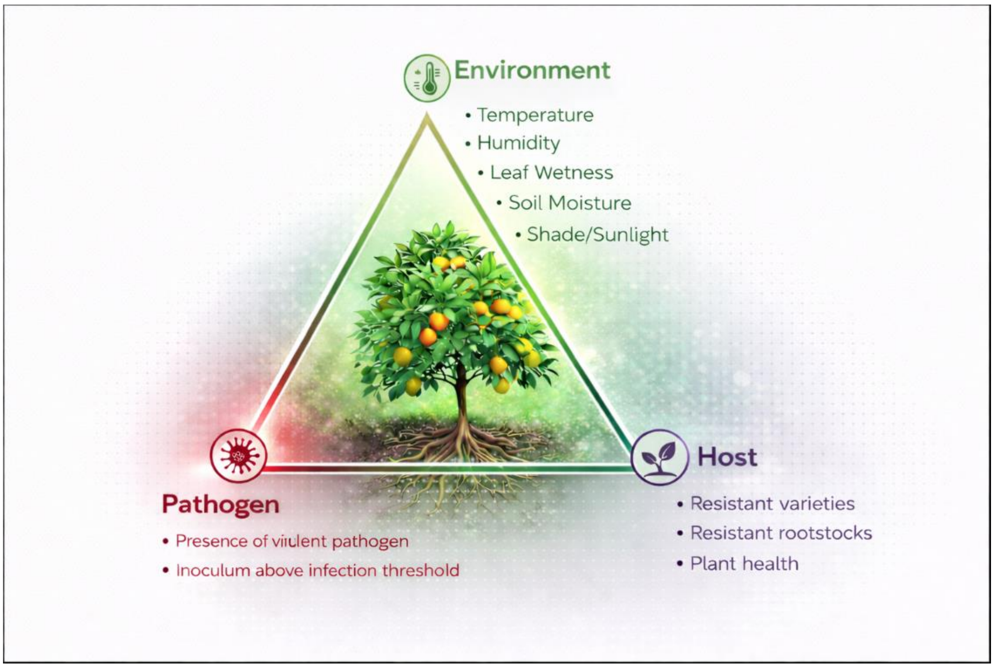

Figure 2: Disease triangle illustrating core requirements for infection and expression of disease (Image credit: T. Thangavel).

The premise of IDM is to disrupt one or more of the three components to reduce or eliminate disease.

Many non-chemical approaches to disrupt or prevent disease are considered IDM cultural control methodologies. An obvious example is the **host** component of the disease triangle where a resistant host cultivar would render the presence of inoculum or disease in the environment a non-issue. No single cultivar will carry resistance to every disease affecting tree health or production of high-quality fruit, however, meaning IDM strategies would be required to manage the remainder of the diseases to which the host is not resistant.

The **pathogen** component is about the presence and amount of virulent pathogen, including inoculum, in the orchard. Cultural control options may include avoid introducing disease with nursery stock or spreading disease using contaminated equipment, or removal and reduction of inoculum from the orchard once the disease is established. Chemical control activities would include strategic use of registered fungicides to complement cultural control measures in place.

The **environmental** component can be more challenging in perennial, field-based farming systems in comparison with annual, protected cropping, media-based farming systems. While much can't be manipulated, this is where key cultural control strategies to manage soil drainage, soil type if appropriate, canopy structure and so on are essential. Alternatively, if the crop could be grown in containers in protected cropping, more environmental management is possible. This is clearly more relevant for nursery applications.
Under IDM, chemical control is not abandoned and is still an important component of a broader disease control strategy. The premise though is a shift from strategy developed around routine,

calendar, or 'just in case' fungicide applications to a targeted, 'needs based' strategy after all cultural control options are in place.

Implementing IDM also requires a shift in attitude and a requirement for a greater understanding of the diseases in the orchard, their lifecycles, favourable environmental conditions, infection periods and so on. It also requires a willingness to use softer chemistries, ensure spray schedules target infection periods, use multi-site products to reduce risk of developing fungicide resistance and strict adherence to label usage, especially for chemistries known to lose efficacy due to fungicide resistance (e.g. group 11 fungicides).

Stages of production when IDM is most useful?

IDM should be incorporated in all stages of production from land selection and ground preparation to mature, fruit-producing orchards. Incorporation of IDM principles early on can significantly increase the success of an orchard and limit the ongoing (never ending!) need for disease management. So, the earlier, the better.

It is acknowledged there is no ability to influence/implement early IDM when buying an established orchard. However, the mature, fruit producing, stage of production is the longest phase of the life of an orchard and requires long term disease and orchard management - implementing IDM here will significantly reduce disease in the orchard and production of saleable fruit. Working with the orchard you have is part of the practical ethos of IDM.

Pre-plant (ground selection, preparation, irrigation)

As any orchardist knows, ground selection and preparation significantly affect the success of a growing and maturing orchard. In terms of IDM, pre-plant components sit largely within the **cultural control** aspect of IDM but also impact soil health which is a key **biological control** component in some systems.

At this stage it is important to understand your specific citrus crop, its nutritional requirements, the conditions it will thrive, tolerate or fail in, the diseases it is susceptible to and so on.

Pre-plant considerations have long term affects. They are integral to seedling and orchard establishment and ongoing tree health. Below ground components of tree management deserve considerable attention. Pre-plant issues are reviewed comprehensively elsewhere and are only touched upon here with respect to IDM and specific citrus diseases.

Soil and water issues are a frequent cause of tree stress which predisposes trees to disease, die back and a general failure to thrive, and stressed trees are often the first to go down. While not discussed here, stressed trees are also more susceptible to insect attack, particularly boring insects which may be linked to some of the undiagnosed dieback diseases.

Some considerations are presented below and, while some aren't strictly cultural control/IDM, they significantly impact orchard health and disease management (highlights Figure 3). Please seek further information on each as appropriate.

Soil Type, Drainage and Slope

Soil type, soil organic matter content and slope affect drainage, water holding capacity, nutritional status of the soil and impacts amount and frequency of irrigation and fertiliser input. These affect all parts of orchard health and fruit production and can't be underestimated. In particular, drainage and water holding capacity impacts water availability (extremes of drought stress or water logging) and whether the soil conditions are conducive to root and collar diseases e.g. *Phytophthora*.

Paddock History

Knowing the cropping history of the block is important, particularly with respect to several important root diseases such as *Armillaria* and *Phytophthora*.

Whole of paddock earth works

This is a considerable commitment in terms of time and money for orchard preparation but is something to consider where drainage is lacking or unacceptable for reasons outlined above. It can mean successful development of a site, but care is needed with respect to disturbance of the soil profile (e.g. mixed horizons can be detrimental to tree growth) and local government environmental considerations.

Mounding

Mounding of rows is more widely adopted in other industries e.g. avocados but should be considered where drainage is compromised or environmental conditions mean the soil profile would be wet for much of the year. The added drainage provided by mounding limits anoxia and conditions conducive to *Phytophthora* diseases in the immediate root zone.

Ripping/plant site preparation

While not strictly cultural control of any particular disease, provision of an open, non-compacted root zone for growing root systems promotes more extensive root growth, the ability to take up more nutrients and water and generally more resilient trees. If deeper ripping is not available, avoid planting into holes with hard, compacted sides which are difficult for small roots to penetrate to avoid a more constricted root mass.

Irrigation

Appropriate irrigation for the soil type and size and age of the tree is important for optimum tree growth, limiting tree stress and keeping available water at reasonably stable levels. For diseases like *Phytophthora*, it is particularly important to avoid continually saturated soil conditions as *Phytophthora* thrives under wet rootzone conditions. Its motile spores also spread freely through the soil in these conditions. Stable water availability and limiting frequent over wetting of the soil profile preventing *Phytophthora* infection and for root health is an example of cultural control.

Irrigation as source of disease (water source)

Clean, disease-free, water sources are important to ensure inoculum isn't applied to the root zone of the trees and the paddock in general. This is particularly important for diseases like *Phytophthora* which have motile spores that spread in free water and have been known to contaminate water storage systems. Ensuring the water source is free of pathogens is an example of cultural control.

Ground Selection	**Drainage** Does it *Drain freely? *Stay excessively wet or dries out quickly? **Soil type/nutritional status** *Allied to drainage *Sand vs loam vs clay **Paddock History** *Previous tree crops or forest present?	*Drought or water-stressed trees are more susceptible to disease *High soil moisture favours soil and water-borne diseases e.g. *Phytophthora* *Constant wetting/drying extremes cause tree stress and root death and favours disease. *Nutritional stress favours disease *Root disease from previous crops e.g. *Armillaria*
Ground Preparation and Irrigation	*Earthworks for whole of paddock drainage *Mounding of rows *Deep ripping trenches or areas around individual tree planting sites *Incorporation of fertilizer or organic material *Irrigation	*Good drainage helps prevent water-borne root diseases *Mounding is additional insurance for limiting water-borne disease e.g. *Phytophthora* *Site appropriate irrigation is key to plant health and maintaining appropriate soil moisture
Sources of Disease Inoculum	Key sources of disease are *Water source *Soil *Implements *Machinery *Old crop material *Nursery stock	*Water can be infected by diseases like *Phytophthora* *Soil-borne diseases can contain disease propagules e.g. *Phytophthora* *Implements and machinery can also spread disease in soil and plant debris from another farm

Figure 3: A summary of key IDM strategies (cultural) and information for orchard establishment. *Brown*) Management component. *Orange*) Practical considerations. *Green*) Effect on plants and disease.

Nursery Stock

Planting healthy, disease-free nursery stock cannot be over emphasised. The quality of nursery stock can make or break orchard establishment with immediate and longer term affects and are a component of the cultural control aspect of IDM.

Soil-borne diseases and root rots

Planting seedlings with diseased roots hinders successful seedling establishment. Symptoms may include failure to thrive, seedling decline or death. Longer-term issues due to root loss or stem cankers/necrosis may persist and require ongoing management.

Root and soil-borne diseases are difficult to treat and often, once present, can only be managed but not eliminated. In addition, planting diseased seedlings may mean introducing a root disease to a previously disease-free paddock, and, even if it was present in low numbers across the paddock, it is now present in the immediate root zone and in place ready to cause ongoing infection.

One of the most important root diseases is *Phytophthora*. It is a soil and water-borne disease that thrives and spreads in wet soil through the free water in the soil profile and will spread with movement of water through the paddock. It is a particular problem in nursery production and buying healthy seedlings from reputable nurseries is key with respect to this disease.

Foliar diseases

Avoid seedlings with any spots, lesions or obvious malformation. As discussed above, depending on the disease it may hinder establishment or introduce a new disease to the farm. Key foliar diseases are ‘Emperor’ brown spot (EBS) and citrus scab. If severe, EBS can cause defoliation of the seedling, hindering establishment.

Pot bound seedlings

Avoid buying and planting pot bound and “J”-rooted seedlings which occurs when the seedling is left in a pot for extended periods instead of being potted on or planted out. Depending on the potting history, the tap root can form a “J” structure followed by one to several tight curls around inside the root zone before expanding into the potting media after being re-potted.

Compromised root systems affect tree health for the long term. Some coiled root systems never venture out into the surrounding soil limiting water and nutrient uptake for the life of the plant. Depending on the soil type and water availability, this will impact young and maturing tree differently. Sometime effects aren’t seen until the tree matures and starts carrying fruit. In addition, these root systems provide less stability, and trees are more susceptible to being uprooted in high winds.

While no particular disease is linked to pot bound plants, pot bound plants are often stressed, are slow to establish and may decline or die years after planting.

Graft Unions

Check the health of the graft unions particularly if buying very young seedlings. Established citrus nurseries generally produce seedlings with high quality grafts, but misaligned grafts, or grafts with dead sections, can affect tree health as the tree matures.

Where to buy

Choose nurseries that specialise in citrus, are known for the citrus component of their production or are, at least, known for the quality plants they grow and sell. Also look for nurseries with Nursery Industry Accreditation Scheme Australia (NIASA) accreditation. This means the nursery must abide by rigorous regulations designed specifically to address nursery hygiene and the production of disease-free plants. The guidelines place a particular focus on *Phytophthora* control and are therefore less likely to sell *Phytophthora* infected plants. Also consider sourcing seed and budwood from Auscitrus to limit seed and bud-transmissible diseases.

Immature Citrus Orchards

The immature citrus orchard is an ideal time to incorporate IDM practices, learn to monitor for tree health and disease, and limit disease development in the growing root zone and canopy while the tree isn't under stress of production. In many ways it is a period of grace where there is time to set the orchard up for future success.

Practices include ensuring adequate irrigation (appropriate soil moisture) to encourage root growth, limit establishment of root disease and implement canopy management to train and open the canopy to light and limit internal humidity.

Managing canopy and foliar diseases in this phase is important to limit the establishment of the disease and its inoculum in the canopy prior to fruit production. For example, inoculum of citrus black spot, 'Emperor' brown spot and other canopy diseases build up over time, so early management will help with curtailing disease in maturing trees.

The immature orchard is also a great stage to learn what is 'normal' in individual orchards. Monitoring skills are essential for pest control, especially if IPM practices are being adopted in addition to IDM.

Mature Orchards

If nothing can be done prior to this phase, all is not lost! Many of the activities addressed above are just as relevant in a mature orchard and implementation will significantly reduce disease and increase tree health and tonnage of saleable fruit.

Immediate activities include ensuring drainage of the paddock is adequate for the crop and the local environment e.g. drainage of flat land in coastal regions may need to be more robust than a sloped orchard inland, ensure irrigation is adequate and the system delivers an even amount of water across the orchard, extensive pruning to remove dead wood and open up the canopy to light and air movement and increase spray penetration.

Pruning removes inoculum of existing diseases, reduces humidity and leaf wetness which are necessary for spore germination and infection, and increases efficacy of any fungicide applications. Reducing tree height will also ensure applied fungicides reach the entire canopy (in areas of the canopy that are not reached by spray, disease will be present, produce inoculum and reinfect the rest of the tree and crop).

IDM for Citrus Fruit and Foliar Diseases

The principals of IDM for citrus diseases mirror those for other industries and revolve around using resistant hosts, managing soil moisture, reducing or removing inoculum, limiting spread on machinery, implements and tools, maintaining good on-farm hygiene, and judicious use of registered fungicides.

The primary twig, leaf and fruit diseases affecting sub-tropical and tropical citrus production will be discussed below with respect to IDM.

Exotic diseases are immediately reportable by law and no attempt should be made to manage these diseases before notifying relevant state bodies of their presence or suspected presence. In the event a suspected exotic disease, please contact the appropriate state agriculture or biosecurity department or call the national Exotic Plant Pest Hotline (1800 084 881) (correct at time of publication).

Anthracnose

The disease

Anthracnose, caused by *Colletotrichum* spp., is responsible for a range of fruit blemishes and necrosis that can render fruit unsaleable. In Australia, while anthracnose is generally attributed to *Colletotrichum gloeosporioides*, the taxonomy of *Colletotrichum* has changed considerably and at least six species have been identified associated with citrus anthracnose. Overseas, a post-bloom fruit drop and an anthracnose on lime is caused by *Colletotrichum acutatum*.

Symptoms and disease cycle

Symptoms can be variable and confused with some of the symptoms of citrus black spot. Lesions can be superficial, reddish brown to brown, spreading across large portions of the fruit, or smaller, sunken black lesions. They can also be in runs or tearstain-like patterns across the fruit surface. The superficial symptoms tend to be a dry decay and can be a problem when immature fruit are degreened, in mature fruit, or as a postharvest problem occurring when fruit are injured, over-mature, experiencing ethylene stress or chilling injury.

The anthracnose pathogen infects and survives in the canopy on dead twigs providing a ready source of inoculum when conditions are favourable. Humidity is the primary driver of spore production in conjunction with warmer temperatures. Conidia are spread by rain splash or overhead irrigation water from canopy to fruit, fruit to fruit, or in running water droplets on individual fruit causing necrosis in tear drop patterns or in runs.

In the presence of moisture and humidity, infection occurs readily and, under rainy or humid conditions, the fungus will sporulate on the surface of lesions. When fresh, the spore masses are orange to pinkish in colour and are diagnostic for a *Colletotrichum* infection. As the symptoms age or dry out, the spore masses can darken and be less distinctive to the naked eye. Symptoms are usually seen on mature, over-ripened, damaged (e.g. mechanical, heat or cold injury) or stored fruit. Symptoms in stored fruit can accelerate quickly and cause considerable rind injury or fruit decay. Alternatively, early season fruit with no signs of colour break, can also develop anthracnose after degreening.

Integrated Disease Management

IDM of anthracnose includes canopy management to remove old wood and dead twigs which are an ongoing source of inoculum, harvest of mature fruit as early as practicable, careful handling to reduce rind injury, as well as processing, packing and storage under optimum conditions. Wet fruit should not be harvested, packed or degreened. As anthracnose infections occur throughout the season but are generally expressed in mature fruit, judicious use of registered protectant fungicides throughout the season is also helpful for control of the disease, particularly so in the case of late harvest.

Figure 4: Anthracnose symptoms (Image credit: DPI Queensland).

Botrytis diseases

The disease
Botrytis diseases, also known as grey mould, are caused by the fungus *Botrytis cinerea* and affect flowers, fruit, twigs (twig blight) and bark, but are considered minor diseases in most growing regions. It is of greater importance in regions with cool, wet conditions, particularly in conjunction with frost and frost damage. Some sources indicate it is primarily a disease of lemons. Economic loss is two-fold due to early fruit drop from infected flowers and subsequent downgrading of damaged, mature fruit.

Symptoms and disease cycle
Botrytis infection appears as fluffy, grey, fungal growth on flowers and very small fruit and on lesions on twigs but also appears as a twig blight where lesions enlarge to girdle and kill twigs. 'Twig blight' is usually limited to twigs of less than 2cm in diameter but infections of larger branches also include gummosis symptoms similar to those seen in *Phytophthora* infections. Fruit surviving to maturity are usually ridged (see Useful Resources).

Infection occurs primarily via wounds and injury sites (especially frost injury sites) by conidia spread by wind and rain (or irrigation) and possibly insects. Healthy tissues are relatively resistant but direct infection occurs in flowers where delicate petals and sepals are particularly susceptible, and in canopy components when inoculum pressure is high. Conidia produced on flowers are thought to be the primary source of inoculum for other flower, fruit and canopy infections.

Temperature and wetness are pivotal for progression of Botrytis diseases, requiring cool, wet conditions for fungal growth and infection. Long periods of wetness from fog, mist or rain promote severe infections when experienced in conjunction with cool temperatures, the optimum temperature for *Botrytis cinerea* being 18˚C. This would, therefore, be an infrequent issue for flowering in tropical and sub-tropical regions and of minor impact in terms of canopy infections.

Integrated Disease Management
IDM of Botrytis diseases lies in inoculum control by effective pruning practices and removal of pruning debris from the orchard in combination with targeted use of registered fungicides administered with respect to rain and fog events.

Brown rot

The disease
Brown rot can be caused by various species of *Phytophthora* including *P. citrophthora*, *P. hibernalis, P. nicotianae*, *P. palmivora* and *P. citricola*. Individual species have different optimum temperatures for growth and infection and therefore predominate in different climatic regions. While all of these species can cause brown rot, some can also cause root rot, collar rot and gummosis in citrus.

Symptoms and disease cycle
On fruit, symptoms are initially seen as a light brown discolouration of the rind. Lesions stay roughly circular as they expand, become darker in colour and may eventually spread over the entire fruit surface, with the rot extending deeply into the flesh. The affected area usually remains firm and leathery. Infected fruit emit a distinctive, pungent odour and fall easily. Under high humidity or during wet conditions, infected fruit become covered by a white 'fungal' growth. Because symptoms often develop during the later stages of fruit maturation, brown rot can pose a significant postharvest issue. Fruit to fruit spread of the disease during storage can also lead to high infection rates in the postharvest phase.

Brown rot can also affect leaves, resulting in blackening or browning of leaves and necrosis of young shoot tips. Symptoms often develop at the tips and along the edges of leaves, and affected leaves often drop while still green.

Phytophthora species which cause brown rot can survive in the soil, in infected roots, in leaf litter and in fallen diseased fruit, depending on the species involved. All *Phytophthora* species produce motile asexual spores (zoospores) which, in the presence of free water, are the primary method of spread and infection by the pathogen, whether it be in the soil or on aerial plant surfaces. During heavy rainfall, spores can be splashed from the soil onto low hanging fruit, leading to fruit infection. Spores produced on infected fruit can also be splashed upwards onto fruit higher in the tree canopy if wet weather continues for long periods. Brown rot development is favoured by rainfall during the later stages of fruit development and maturation.

Integrated Disease Management
A combination of cultural practices and fungicide application in the field, as well as postharvest treatments, are the basis for brown rot management. Field practices recommended for the control of all *Phytophthora* diseases of citrus (such as root rot, collar rot and gummosis) will also help with brown rot control by reducing inoculum levels in the soil and in the canopy. These practices include using clean nursery stock and resistant rootstocks when establishing orchards, providing good soil drainage and plant nutrition, and optimisation of irrigation.

Specific recommendations for brown rot control include avoidance of over-watering and direct contact of water from sprinklers onto trunks for extended periods, removal of lower limbs (skirting) to improve ventilation and drying under trees, removal of mulch directly in contact with the trunk, and removal of weeds under trees. Application of registered fungicides according to prevailing weather conditions, especially spraying the trunk and lower limbs to a height of approximately 1.5m, will help to reduce inoculum.

Figure 5: Phytophthora Brown Rot of L) Fruit and R) Leaves. (Image credits: Kathy Grice)

Citrus Black Spot (CBS)

The disease
Citrus black spot (CBS), caused by the fungal pathogen *Phyllosticta citricarpa*, is a major citrus disease worldwide affecting almost all species and varieties of citrus. In Australia, it is particularly relevant in sub-tropical and tropical production areas and is reported to be responsible for over $80M in losses per annum through export restrictions, fungicide applications and fruit damage (Drenth, 2013). The major citrus crops, lemon, mandarin and orange, are susceptible. It has also been detected in limes which were previously deemed tolerant. It is a difficult disease to manage in the sense that apparently symptom-free fruit can develop spots or necrosis after harvest in postharvest storage.

Symptoms and disease cycle
CBS has up to six symptom types on fruit and is responsible for considerable loss of saleable fruit. The symptom types are hard spot, freckle spot, virulent spot, false melanose, lacy spot and cracked spot. While all symptom types can affect fruit, hard spot is the most well-known and frequently detected with its small, sunken, often circular lesions. Mature lesions are grey or grey-brown, have a defined border which may be red to black depending on the citrus variety, and usually have small black 'dots' visible within the grey tissue. There may be one to over a hundred lesions per piece of fruit.

The 'dots' in the dead tissue of the lesion are fungal fruiting bodies called pycnidia which produce masses of asexual spores called conidia. The conidia are dispersed by rain or irrigation splash and go on to form new infections on leaves or fruit. Each pycnidium can produce hundreds if not thousands of conidia. Pycnidia can also be formed on branches and twigs within the canopy from year to year, as well as in leaf litter.

A second source of inoculum are sexual spores called ascospores that are usually produced in leaf litter. Ascospores are produced in fungal fruiting bodies called pseudothecia and are released during wet conditions and spread by air currents. Ascospores have traditionally been considered the major source of infection for CBS, but recent research has challenged this thinking for our local conditions. A study monitoring fruiting body levels in the leaf litter of citrus orchards in subtropical Queensland found that the pycnidia are the dominant fungal fruiting body present in leaf litter at the beginning of the fruit season, whereas pseudothecia tended to predominate in late December to early January (Tran et al, 2020). Disease incidence, however, could not be correlated with numbers of either ascospores (from pseudothecia) or conidia (from pycnidia) in leaf litter, suggesting that other sources of inoculum may play a more important role in the disease cycle. Subsequent research (Project CT20009) has illustrated that branch inoculum within the tree canopy significantly influences the amount of disease detected in fruit.

Citrus fruit are most susceptible to infection by *P. citricarpa* within four to five months after fruit set, but the critical period may vary according to variety and tree age. Infections then remain latent until the fruit matures, when visible symptoms appear. Environmental stress can exacerbate symptom expression.

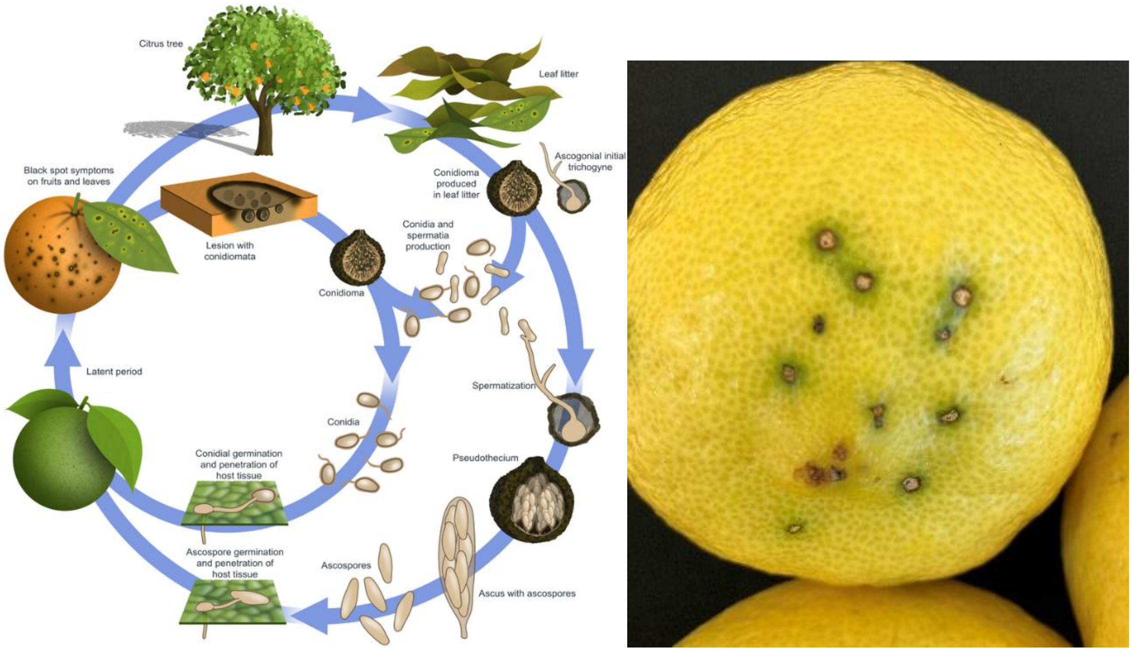

Figure 6: L) Lifecycle of *Phyllosticta citricarpa* (Image: Guarnaccia *et al*., 2019) R) Hard spot of lemon (Image credit: Kaylene Bransgrove).

Spore (conidia) production and infection is favoured by temperatures of 25°C and over in combination with rainfall or leaf and fruit wetness. The infection period for fruit varies slightly between variety but is for up to the first four to five months after petal-fall.

Integrated Disease Management

The understanding of effective IDM measures for CBS has changed with the knowledge provided by the trial work of CT20009 that built upon the outcomes of CT13021. Prior to this the key IDM component was managing the leaf litter to control ascospores and reinfection of the tree and fruit from the litter. It was previously known that conidia were produced in the canopy but the importance in the disease cycle was significantly underestimated. CBS inoculum within the tree canopy is now known to substantially increase the amount of disease detected in fruit and reduce the amount of saleable fruit.

Following this, the key means of IDM management of CBS is regular canopy management include structural management to increase airflow and spray penetration in combination with removal of all pruning debris from the canopy. Further research is planned to ascertain the maximum time between pruning and pruning debris removal before fruit quality is impacted (i.e. time before conidia are formed on and shed from the canopy to fruit).

While it is now understood that the sexual phase is a component of inoculum production rather than the major source, management of leaf litter during conditions conducive to ascospore production is recommended. Litter degradation and mulching to prevent spore production and dispersal to the canopy respectively are key components as is limiting fungicide run-off (shown to reduce litter degradation). Litter removal has proven to be less effective, difficult and has host of negative follow-on consequences.

Strategic application of registered protectant fungicides during the first four to five months after petal fall have been shown to provide excellent control of CBS in mandarin and are a recommended counterpart to canopy hygiene.

Figure 7: Top left) Speckle blotch. Top right) Freckle spot. Bottom left) Virulent or Galloping spot/symptom. Bottom right) Close up of Hard spot including pycnidia within the hard spot lesions. (Image credits: DPI Queensland)

Citrus or Lemon Scab

The disease

Citrus or Lemon Scab is caused by the fungus *Elsinoe fawcettii* AUTHOR but may be listed in older literature as *Sphaceloma fawcettii*, or *Elsinoe*- or *Sphaceloma fawcettii* var. *scabiosa*. Only the anamorph (asexual stage) is found in Australia. Lemon scab was once also called Tyron's Scab and is now considered a part of the broader citrus scab group. While lemons are generally the most susceptible, other citrus varieties including mandarin and grapefruit can be affected.

Symptoms and disease cycle

Symptoms can be found on fruit, leaves and twigs and when mature are raised, warty or cracked and grey to brown in colour. Some sources note that when scabs are developing, they are only slightly raised, are pink to light brown. Symptoms are subtly different between citrus species and varieties as are symptoms on young versus older tissues.

The scab symptom itself is a combination of plant tissue and fungal matter and produces conidia from the surface of the scab when conditions are suitable. The conidia are spread by rain (or irrigation) or wind. Infection and development are favoured at temperatures of 24-27˚C but can occur between 21-30˚C. Conidia can be produced continuously under conducive conditions. Newly emerged leaves are susceptible as are very young fruit. Information varies for the duration of susceptibility of young fruit from 6 weeks to three months or up to 3 cm in diameter. Important to note is infection periods are very short and only four-six hours in duration in the presence of leaf wetness is required.

Integrated Disease Management

IDM of citrus scab comprises a combination of canopy management (pruning) to remove infected material and spraying with protectant fungicides during periods of susceptibility. Due to the very short infection period, continuously monitoring the weather and spraying appropriately is essential to provide protection.

Figure 8: Scab symptoms on L) fruit R) leaf material (Image credits: Kathy Grice).

‘Emperor’ Brown Spot (EBS)

The disease

‘Emperor’ Brown Spot (EBS), also known as Alternaria Brown Spot (ABS), is caused by fungi in the genus the fungus *Alternaria* and is most frequently attributed to *Alternaria alternata*, but may be listed in other literature as *Alternaria citri* or *A. alternata* pv. *citri*. Many other species of *Alternaria* pathogenic to mandarin and lemon have also been described but the identity of the species affecting citrus in Australia has not been re-examined recently.

EBS was first detected in Australia on ‘Emperor’ mandarin in 1903 and is a disease of foliage and fruit causing considerable loss of premium-grade fruit. It is particularly a problem in warm, humid regions where late autumn rain and fog extend leaf and fruit wetness periods and exacerbate infection and symptom production. In Australia, this pertains primarily to coastal production areas in the Central Burnett growing region and northern NSW.

Other *Alternaria*-induced diseases include Alternaria core rot, stem-end rot (discussed under postharvest rots), and leaf spot of rough lemon and mancha foliar de los citricos which is not discussed here.

Symptoms and disease cycle

Young leaves and new shoots are highly susceptible to infection by *Alternaria*. Initial symptoms are very small brown or brown-to-black spots surrounded by a chlorotic halo. The spots may be on leaf margins or across the leaf surface, with the severity of infection dependent on the temperature and duration of leaf wetness at time of infection. The necrotic spots can enlarge significantly, consuming most of the leaf. The necrosis is caused primarily by a mobile toxin produced by the fungus and therefore sometimes the symptoms will also include vein/vascular necrosis. If infection is severe, considerable leaf drop may occur as can twig dieback.

Fruit are also highly susceptible when very young, and while fruit generally become more resistant as they approach maturity, late season infections can be severe in areas with autumn rains, humidity and dew. Infected fruitlets may abscise after petal fall causing early loss of yield. Lesions on older fruit are variable from small, dark spots, to a spreading brown necrosis to corky cankerous looking lesions. The ‘cork’ may excise from the lesion leaving a crater. In extreme circumstances the fungus will grow beyond the lesion and very large, haloed lesions may form. This is not necessarily common and the fruit would normally drop prior to maturity/harvest.

Figure 9: EBS symptoms L) Early infections on a young leaf C) advancing lesion on mature leaf R) extensive infection. (Image Credits: L) Tamil Thangavel C) & R) Tony Cooke)

Figure 10: EBS symptoms on fruit L) young fruit (Image credit: Tamil Thangavel) C) developing fruit (Image credit: Emily Pattison) R) mature fruit (Image credit: Tamil Thangavel).

The EBS disease cycle occurs in the canopy on twigs and leaves and to a lesser degree on fallen leaves. Conidia (asexual spores) are produced on lesions and are spread by wind and rain splash within the canopy and onto fruit. Conditions that promote infection and lesion development are 20-27°C and extended periods of leaf wetness. As temperatures decrease, even longer periods of leaf wetness are required for significant infection. Conidia are melanised and survive for long periods in the canopy meaning inoculum is present and viable whenever infection conditions present.

It is important to note that EBS is also a disease of seedlings - constant production of new leaves and shoots in the nursery in combination with leaf wetness from irrigation and high humidity in tunnels and shade houses are the perfect environment for infection.

Integrated Disease Management

IDM of EBS has several components. If the orchard is yet to be established, IDM begins with use of healthy, symptomless nursery stock. If the chosen cultivar is known to be susceptible, avoid establishment of areas of the farm where fog prevails and leaf wetness can be extended due to lack of morning sunlight. Increased tree spacing and consistent skirting are suggested as are limiting excessive production of flush, especially in periods that favour infection.

Once established, pruning to open the canopy to air flow and fungicide application is important, as is routine pruning to remove dead and infected wood and removal of pruning debris from the canopy.

Fungicide control is a necessary component of controlling EBS and should be targeted towards known periods of increased susceptibility. Lowering the inoculum in the canopy by pruning and canopy hygiene will increase efficacy of applied fungicides.

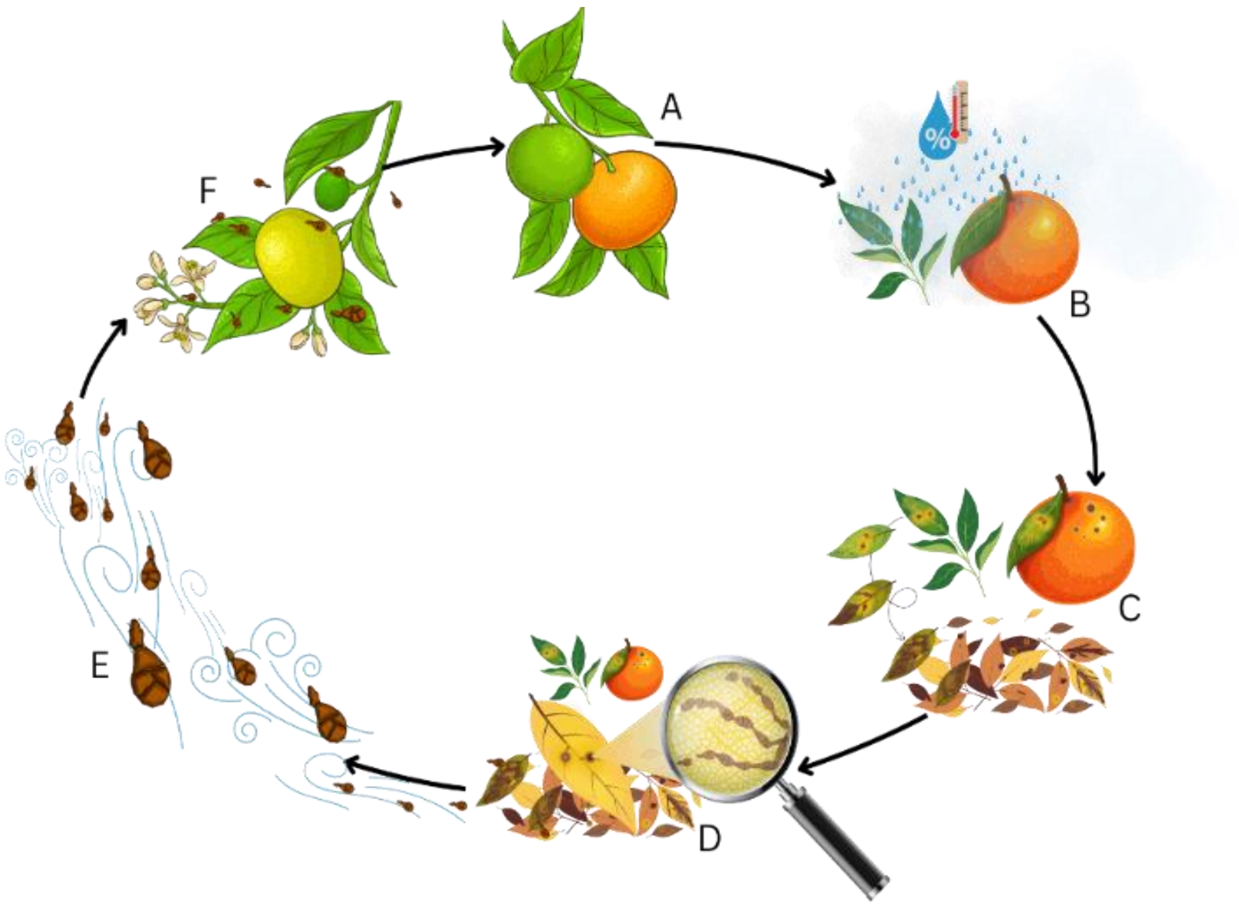

Figure 11: Disease cycle of EBS. A) Infected but symptom-free fruit B) Temperature, moisture, humidity conducive for symptom development and further infection C) Symptom production D) Inoculum (conidia) production E) Dispersal of conidia by wind and rain onto F) Foliage, flowers and fruit for ongoing infection. (Image credit: Dale Bennet /Emily Pattison)

Greasy spot

The disease

Greasy spot is caused by *Zasmidium citri* but will be listed in older literature as *Mycosphaerella citri*. It is found worldwide and, while it can cause a rind blotch symptom in grapefruit, it is primarily a leaf disease and is present in most citrus. It is common in most orchards, usually has little impact on fruit production, but if foliar symptoms are severe, leaf drop can occur and requires more targeted management. Greasy spot is more prevalent in summer through to late autumn in areas with warm and humid conditions.

Symptoms and disease cycle

Symptoms progress from yellow to tan blisters or raised areas to darker brown raised areas on the underside of the leaf. The spots darken with age and become 'greasy' in appearance. The spots don't, however, become necrotic but remain dark and greasy and are a useful diagnostic character. Early symptoms can also include yellow spots on the upper leaf surfaces and tiny black specks eventually surrounded by a yellow halo on the underside. Where the symptoms are severe and cause significant leaf drop, fruit yield and size may be affected due to lack of tree vigour.

Ascospores (sexual spores) are formed on lesions on fallen leaves in periods of wetting and drying (including irrigation), are released in warm humid conditions and infect mature leaves. Ascospores are ejected when the fruiting body is wet (rain, irrigation or dew) and are considered the primary means of infection by the disease. A second spore type (conidia (asexual spores)) can be formed on the underside of attached leaves and are dispersed by wind/rain/splash but are not thought to contribute significantly to disease. It is possible for fruit to be infected but symptoms on fruit are uncommon.

The infection period is dependent on a combination of when leaf fall occurs and when warm, humid/wet conditions for spore development and release are experienced. Depending on the region and the irrigation practices, this typically occurs in spring and summer before leaf litter has decomposed. Sporulation can occur through autumn if there are ongoing leaf fall and conducive conditions. Symptoms take between three to six months to develop, and, in Australia, are more prevalent in autumn and where autumn rainfall and dew is common.

Integrated Disease Management

The mainstay IDM of greasy spot is cultural control management of leaf litter to prevent ongoing sporulation and new infections. This can be done by removal of leaf litter or mulching to cover litter and prevent spore dispersal. A registered fungicide programme throughout summer and autumn will also significantly reduce the incidence and ongoing infection by *Zasmidium*.

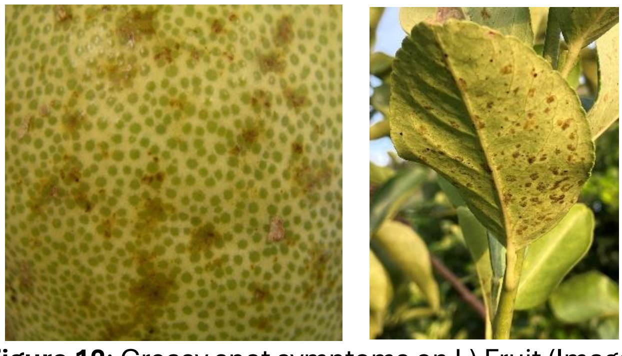

Figure 12: Greasy spot symptoms on L) Fruit (Image credit: Kathy Grice) and R) Leaf material (Image credit: Kaylene Bransgrove).

Melanose

The disease
Melanose is a twig, leaf and fruit disease caused by the fungus *Diaporthe citri* in humid coastal growing regions worldwide. While symptoms on fruit are superficial, they can be severe, downgrade fruit quality and are responsible for loss in premium-fruit grade sales. The disease is problematic in the warm and humid sub-tropics and tropics but is not seen in dry, inland growing regions. Therefore, coastal and near-coastal citrus in Queensland is most at risk of this disease. Fruit, depending on variety, are reportedly susceptible for up to the first five months after petal-fall. *Diaporthe citri* also causes a fruit stem-end disease which is discussed in the post-harvest section.

Symptoms and disease cycle
Symptoms on fruit, leaves and twigs vary but are all raised or rough to touch. Initial leaf symptoms are a small 'pustule' found within yellowing tissue before the pustule darkens. The halo is usually retained. Immature leaves are the most susceptible and mature, fully expanded leaves are apparently resistant. On fruit, symptoms are usually small, raised, reddish-brown to black in colour and can appear within a week of infection. As the spores are spread by water, the symptoms often appear in runs on fruit. Depending on the degree of infection, the symptoms may coalesce and/or form a crust which can later crack as the fruit enlarges.

While the disease affects leaves and fruit, the ongoing lifecycle and production of inoculum occurs in the canopy on twigs and dead wood. Spores are spread to leaves and fruit by splash or drip (rain or irrigation). Rainfall and humidity are required for infection and disease development. In comparison with other fungal diseases, conidia of *Diaporthe citri* require longer periods of leaf wetness for germination and infection, but this is also temperature dependent, with longer leaf wetness periods needed as temperatures decrease (e.g. 10-12 hours at 25-30°C or 18-24 hours at 15°C.

Integrated Disease Management
Management of dead wood including twigs in the canopy to remove as much inoculum as possible is recommended in combination with judicious use of fungicides such as copper formulations. In areas where this disease is problematic, management can be challenging due ongoing production of spores from remaining dead material in the canopy and the need to spray regularly to protect developing fruit.

Figure 13: Melanose on citrus L) leaves and R) fruit (Image credits: DPI Queensland)

Pink Disease

The disease

Pink disease, caused by *Necator salmonicolor*, is a canopy disease of all citrus and many other shrubs and trees. The causal organism has had several name changes and may be found in other literature under its synonyms *Erythricium salmonicolor* or *Corticium salmonicolor*. Pink disease does not directly affect fruit but causes loss of production due to die back of parts of the canopy. It is considered a minor disease as a whole but can become a problem in tropical production systems.

Symptoms and disease cycle

In warm, wet/humid conditions the fungus grows as a hyphal network along twigs and branches and forms a salmon to pink coloured sheath by which it is easily identified. When the fungus dries out with seasonal change, the pink colour fades and it is more difficult to spot in the canopy.

Pink disease can progress quickly along twigs and branches resulting in branch death. Early symptoms include chlorosis or necrosis of a sector of a tree. Where the fungus is present on many branches, the canopy may defoliate and degrade quite rapidly and severe infections can kill entire trees. In northern Australia, the disease is seen regularly throughout the wet season.

Integrated Disease Management

IDM of Pink disease is achieved by pruning out diseased limbs, ensuring the point of pruning is below the last visible area of pink mycelium and the wood shows no signs of internal necrosis. The pruning debris should be burnt to prevent further spread of the disease in the orchard. Adopting regular pruning practices to maintain an open canopy is also ideal as it lowers humidity in the canopy and limits the conditions favourable for growth. Application of copper fungicides is recommended after pruning but success is dependent on adequate spray penetration into the canopy and coverage of the inner canopy and remaining branches.

Figure 14: Symptoms of Pink disease on Tahitian lime L) Mycelial growth on branches R) Early sectoring symptoms (Image credits: Kaylene Bransgrove)

Septoria Spot

The disease
Septoria Spot is caused by *Septoria citri* and is of more importance in citrus growing regions of southern Australia. Overseas literature states several species of *Septoria* can cause symptoms but that it is a disease of low importance.

Symptoms and disease cycle
Leaf symptoms include small, brown to black spots that are raised or blister-like and develop a yellow halo. Symptoms on fruit are sunken necrotic spots, often small but up to several millimetres in diameter. Early symptoms are tan with a green margin that become red to pale brown with fruit maturity. Fruiting bodies (pycnidia) can form in the lesions and appear as small black dots. Symptoms may appear before or after harvest (storage).

This is another disease that lives primarily in dead wood and twigs in the canopy and the conidia produced there are spread by rain or irrigation splash to leaves and fruit. The initial stages of infection typically takes place in late summer or autumn following wet conditions, while the fruit is still green. Making it difficult to manage, the fungus becomes latent (inactive) and symptoms may not be visible for up to six months after infection. Low temperatures and especially frost reactivates infections, leading to symptom development, usually in late winter and early spring when the fruit colours. It has been reported that symptoms are often more severe on the southern side of trees.

Integrated Disease Management
Good canopy management (including tree skirting and removal of fallen fruit and leaves) is useful for limiting the amount of inoculum present for ongoing infection as is use of copper fungicides, with a particular focus on late summer/early autumn applications before autumn rainfall. Due to relationship of symptom development with respect to cold temperatures and exposure to frost, frost management/protection is useful if possible. Fruit tissue with cold damage or mechanical injury is susceptible to infection in the presence of moisture from rain or dew.

Postharvest development of Septoria spot can occur if fruit with early infections are not detected and removed from the packing line, although symptoms will typically be confined to the rind. Nevertheless, rind injury will result in downgraded fruit quality. Enlarged lesions may also develop on over-mature fruit on the tree. For this reason, fruit should not be allowed to hang on the tree for too long.

Sooty Mould

The disease
Sooty Mould is a fungal disease caused by *Capnodium citri* and several to many other dark-coloured fungal organisms and affects leaves and fruit in all citrus growing regions. The fungal growth is superficial but in very severe infections it can indirectly impact tree health and fruit production by limiting photosynthesis. Sooty mould can be difficult to remove from some varieties in a packhouse setting and therefore affect pack out processes and volumes.

Symptoms and disease cycle
Symptoms include a dark, superficial, fungal growth on leaves, twigs and fruit. It does not infect the host itself but lives wholly on the surface of leaves and fruit on honeydew produced by aphids, soft scale, mealybug and whiteflies among others. Inoculum is ubiquitous in the environment rather than in the canopy or orchard but, without the presence of honeydew as a food source, the 'infection' will not occur.

Integrated Disease Management
IDM of sooty mould is wholly based upon control of the honeydew producing insects using registered insecticides or softer, IDM friendly options such as horticultural oils.

Figure 15: Sooty mould symptoms on L) fruit and R) leaves.
(Image credits: L) DPI Queensland. R) Kaylene Bransgrove).

Sooty Blotch and Flyspeck

The disease

Citrus literature indicates sooty blotch is caused by the fungus *Gloeodes pomigena* and/or *Stomiopeltis citri* and flyspeck by *Leptothyrium pomi*, while the broader literature indicates a vast number of fungal species cause blotch or flyspeck in different crops and countries. The identity of citrus sooty blotch and flyspeck in Australia requires investigation. Both diseases are considered minor but both can be difficult to remove from fruit surfaces, however, and can downgrade fruit quality.

Symptoms and disease cycle

Sooty blotch symptoms consist of a fine network of mycelium on the surface of the tissue, with or without darker spots within the blotch. The blotch may be light brown to grey to black in colour and will have irregular margins. The fungus lives in the canopy on infected twigs and infection and symptom production on fruit occurs in warm, wet and/or humid conditions.

Flyspeck symptoms are similar except the hyphae is much less dense and difficult to see, with the predominant characteristic being the fungal fruiting bodies which have a flyspeck appearance. This disease is also favoured by wet and humid conditions.

Integrated Disease Management

IDM of these diseases include canopy management to remove available inoculum and judicious use of registered fungicides in warm, wet/humid conditions. Chemical control measures in place for citrus black spot should provide adequate management of this disease.

Figure 16: Sooty blotch symptoms on mature fruit. (Image credit: DPI Queensland.)

Postharvest fruit rot diseases

Anthracnose

The disease
This disease caused by *Colletotrichum* was discussed above, but it is worth noting it briefly as a postharvest disease as, if present, symptoms and the associated decay accelerate quickly as fruit becomes over-mature or stored. Please refer to the anthracnose section above.

Symptoms and disease cycle
Infection is from conidia washed from the canopy by rain or irrigation. It can occur throughout the growing season but remains latent (inactive) and symptomless until fruit are mature and when mature skin is injured (including bruising). It becomes a particular problem postharvest as apparently healthy fruit can develop symptoms in storage.

Integrated Disease Management
IDM is centred around control of inoculum in the orchard by canopy management followed by effective postharvest sanitation and fungicides.

Black core rot (*Alternaria*)

The disease

Black core rot (also known as centre rot) is a fruit disease caused by *Alternaria alternata*, also the causal agent of 'Emperor' Brown Spot and Alternaria leaf spot. The identity of the causal agent, however, is currently under review but it appears that non-toxin producing *A. alternata* may cause Black Core Rot while toxin producing isolates cause 'Emperor' Brown Spot. The disease is of higher importance in regions of southern Australia but can occur in sub-tropical and tropical growing regions. Literature indicates it can be an important production issue in Navel oranges and Ellendale tangors, also reflecting a larger southern production base of these varieties.

Symptoms and disease cycle

The disease is expressed internally as a dark, black rotten core that is usually undetectable unless fruit are opened. It is therefore a significant postharvest issue when it is present. Fruit affected by black core rot may cause premature fruit drop but the greatest impact is postharvest.

Distribution of the conidia that later cause disease occurs very early in the growing season when fruit are small and immature. Conidia are spread from where they are produced in the canopy by wind and rain to young fruit and, where they lodge underneath the 'button' (stem end) or in imperfections in the navel (stylar/blossom) of fruit. Here they remain latent until fruit maturity. At this time, when the 'button' dies, the fungus can enter the fruit and the likelihood of this is greater in wet/humid weather. Latent infections at the navel end may invade fruit via growth cracks. Infection can also occur through mechanical wounds in the rind. This infection pathway can lead to the development of external as well as internal symptoms. Mealybug infestations in the navel of fruit appears to be associated with a greater prevalence of disease. Infection is also increased where fruit are left over-mature or stored for long periods.

Integrated Disease Management

Canopy management and control of canopy borne inoculum is essential for IDM of black core rot to limit the inoculum produced in and available for spread to young fruit. Overall tree health is important as plant stress can increase fruit splitting, providing entry points for the pathogen. Controlling mealybug infestations in the orchard may help to reduce disease occurrence in some cultivars. Applying registered postharvest fungicide products will provide some control of the disease. Fruit should not be stored for long periods, and over-mature should be marketed promptly.

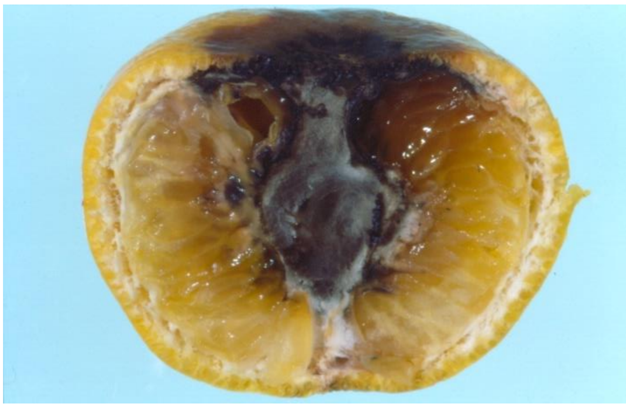

Figure 17: Black core rot symptoms. (Image credit: DPI Queensland.)

Blue and green moulds

The disease

These two diseases are treated together here due to similarity of behaviour and consequences for stored fruit. They are caused by species of *Penicillium*, blue mould by *Penicillium italicum* and green mould by *Penicillium digitatum* and are both very important with respect to storage and shelf-life of mature fruit, although green mould is generally considered to be the most serious of the two diseases. While they can be present on fruit simultaneously, green mould is usually dominant in fruit held at above 10°C. Conversely, blue mould tolerates low temperatures and is known to spread in and dominate infections in cool-stored fruit.

Symptoms and disease cycle

Symptoms begin as watery, soft areas that may be discoloured or paler than the surrounding tissue and, in the very early stages, may look like early symptoms of sour rot. The areas enlarge, quickly rotting the rind and fruit.

Blue mould symptoms expand more slowly than those of green mould and may be overgrown or the minor component where both disease types are present in storage. Both initially grow on the surface of the fruit as a white, powdery mass or mycelial growth before producing masses of blue to brownish olive or olivaceous green spores with age. An outer ring of white mycelium remains at the growing margin of the lesion or rot in both diseases. The white margin of fruit affected by green mould is typically wider than that of blue mould. Both diseases sporulate prolifically, producing large sources of inoculum very quickly.

In-field inoculum is attributed to rotting fruit on the orchard floor while pack shed infection is from inoculum on the pack-shed floor or equipment. Both diseases are spread by wind can be carried from the packshed floor/environs onto what had otherwise been clean fruit. In the orchard, spores could also be spread by rain splash to low hanging fruit or from fruit to fruit if rotting fruit are caught in the canopy. In packed fruit after harvest, fruit to fruit spread can occur leading to nests of decaying fruit. When affected fruit are disturbed, clouds of spores can rise up in the air.

Infection occurs through wounds of the rind and even the smallest amount of damage from picking (e.g. damage to glands) can be enough for infection to establish. This damage can happen in the field, during harvest or in handling in the pack shed.

Temperature plays a considerable role in disease development. Both fungi grow quickly between 20 and 25°C but growth still occurs below and above this range. As mentioned above, blue mould is more tolerant of temperatures around 10°C though growth is still minimal compared with higher ambient temperatures.

Integrated Disease Management

The core component of IDM of blue and green moulds lies in limiting the time rotting fruit is present on orchard floors (where possible), scrupulous sanitation of pack shed floors, walls, bins and equipment and disposal of fruit far from the pack shed. Alongside this, every care must be taken to limit rind damage from field to pack out and keep fruit cool to limit rapid development of both moulds. Picking wet or damp fruit should be avoided as turgid fruit are more prone to rind injury. Postharvest fungicide treatment within 24 hours of harvest is imperative to further reduce risk of infection and development of either rot. Fruit should be washed prior to fungicide application. Fruit should also be stored at recommended temperatures after harvest, and any infected fruit should be promptly removed from storage or display areas.

Figure 18: Blue and green mould on mature fruit. (Image credit: DPI Queensland.)

Sour rot

The disease
Sour rot is a disease of mature and mature postharvest (including stored) fruit caused by the fungus *Geotrichum candidum*. It causes significant loss of marketable fruit especially in wet seasons or regions and where these conditions coincide with harvest. It is possible to have mixed infections of *G. candidatum* and *Penicillium* spp., exacerbating the rot and loss of fruit.

Symptoms and disease cycle
Symptoms vary slightly between citrus varieties but are always a watery rot, paler than non-affected tissue. The area is very soft to touch, easy to damage and necrosis progresses quickly. Very early symptoms may look like symptoms of the blue and green mould fungi, but the cuticle can be removed from the epidermis of the rind much more easily in sour rot infections than in blue/green mould infections. When advanced, the surface of the affected area may be covered in a white fungal growth that may have a 'yeasty', wrinkled appearance. Affected fruit have a distinctive yeasty and vinegar-like smell, and larvae of ferment flies may be present in decayed tissue.

Geotrichum lives in soil and dust and is spread by wind and rain. It can also be spread after harvest in the field or pack shed by wind-borne dust, or water or fungicide tanks contaminated by infested soil. Infection occurs through rind injuries or where fruit are touching in storage and is promoted by warm wet conditions, particularly where temperatures fall between 25-30°C. Even healthy fruit can be infected in long term storage by adjacent symptomatic fruit, making postharvest procedures a priority. Disease susceptibility is greater in ripe or over-mature fruit.

Integrated Disease Management
Several means of IDM of sour rot are available and include limiting dirt/dust in packing sheds, avoid injury to the rind of mature fruit (minimising picking injuries), cooling fruit as soon as possible postharvest and prior to transport, and limiting long-term storage of fruit. It has been reported that sour rot infection is greater when fruit are harvested soon after rainfall (or irrigation) compared to fruit harvested a number of weeks later. In addition, application of registered postharvest fungicide treatments within 24 hours of harvest is essential.

Figure 19: Sour rot of lemon. (Image credit: DPI Queensland.)

Stem-end rots

Several fungi can cause stem-end rots and include Alternaria Stem-End Rot (SER), Diplodia SER and Diaporthe SER, the latter two being possibly the most well-known of the stem-end rot diseases.

The diseases

Diplodia SER is caused by *Lasiodiplodia theobromae* but due to taxonomic changes may be listed in older literature as *Botryodiplodia theobromae*, *Botryodiplodia rhodina* or *Diplodia theobromae*. Diaporthe SER is caused by *Diaporthe citri*, discussed previously under melanose, and is also called Phomopsis SER. Diplodia and Diaporthe SER both cause rot and downgrading of fruit that is rarely seen until ripening begins whether this is in the field or postharvest. These diseases can also be more problematic if excessive ethylene concentrations are used in varieties that require degreening. Ethylene enhances button abscission, and the high temperatures and humidity used in degreening provide ideal conditions for disease development.

Alternaria SER is caused by *Alternaria alternata*, which is also the causal agent of black core rot. For both Alternaria SER and black core rot, the strain of *Alternaria alternata* involved is believed to be non-toxin producing, in contrast to the toxin-producing strain which causes 'Emperor' brown spot. Alternaria SER can cause premature fruit drop but is usually seen in stored fruit and is doubly problematic because even small infections can cause unpalatable changes to the flavour profile of the fruit.

Symptoms and disease cycle

Infection occurs at the end of the stem for all diseases but varies with respect to when symptoms develop or progress.

Infection by *Diaporthe* occurs throughout the season. As melanose, *Diaporthe* infections usually result in small, raised symptoms that do not progress to rot. As a stem-end rot, however, it is a serious problem, particularly in warm, wet and/or humid conditions. Infection of necrotic tissue of the button occurs during the growing season but remains inactive (latent) until fruit ripening/harvest where it spreads from the stem-end through the previously healthy and symptomless fruit tissue.

Similarly, latent infections by *Lasiodiplodia* become established in necrotic button tissue during the season and progress after harvest. The rot starts from the stem-end where symptoms are seen externally on the rind but can then progress internally through the fruit core very quickly to reach the stylar (navel) end of fruit. This is thought to be a faster infection pathway than through the rind. As a result, external symptoms may be seen at both ends of the fruit, with healthy rind in between, before the rot covers the entire fruit surface. In other cases, however, the rot is visible externally all the way from the stem- to the stylar-end. Less commonly *Lasiodiplodia* can infect fruit through wounds on the side or stylar-end of fruit.

In the early stages of disease progression, these two diseases can be difficult to impossible to distinguish from each other. As they progress, Diplodia SER symptoms develop a clear line or demarcation between the infected and healthy tissues while Diaporthe SER moves unevenly throughout the fruit and has an indistinct advancing margin. As Diplodia SER progresses, it often spreads from the stem-end in finger-like projections and tends to be darker in colour than Diaporthe SER lesions. *Lasiodiplodia theobromae* is a very fast-growing pathogen at its optimum growth temperature of 28-30°C, completely consuming the fruit in a few days. Figure 20 below illustrates less commonly seen symptoms (not finger-like projections). A link is provided in the resources section for photographs of typical symptoms. *Phomopsis citri* has a lower optimum temperature of 23-24°C for disease development. Infection by *Alternaria* occurs in a similar way to *Diaporthe* and *Lasiodiplodia* - by establishing latent infections of the stem button during the growing season that develop further when the button senesces. Alternaria SER symptoms are similar in appearance to those of Diaporthe and Lasiodiplodia stem-end rots in the early stages.

Inoculum of *Alternaria* was discussed under 'Emperor' Brown Spot and *Diaporthe citri* was discussed under melanose. *Lasiodiplodia theobromae* also completes its lifecycle in the canopy on dead wood and twigs with very large numbers of conidia produced throughout the growing season. It is associated with canopy dieback symptoms in general and its ability to produce copious amounts of inoculum where dead wood is present is well known.

Integrated Disease Management
Disease management for SER starts with effective canopy management and ongoing removal of dead wood and twigs to limit the copious production of spores developing on stem-end tissue. This is particularly important in these diseases because there are usually no symptoms of either in fruit until ripening. Protection of susceptible tissue through the growing season, particularly at half to three quarters petal fall, with recommended fungicides is advised. Avoid letting fruit hang on the tree too long, as over-mature fruit will have senescent stem buttons which support progression of latent infections. For Alternaria SER, the causal agent is a relatively weak pathogen, and therefore symptoms tend to develop in fruit stressed by drought or frost. Maintaining optimum tree and fruit health will aid in disease prevention.

After harvest, and before degreening, apply a recommended postharvest fungicide as soon as possible. Prompt marketing and maintenance of the cool chain through transport and storage is critical for SER management.

Figure 20: Diplodia rot of citrus (Image credit: DPI)

Useful Resources

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