Fungicides, Resistance and their Management in Production Nurseries

Fungicides work by stopping or inhibiting fungal growth, sporulation or germination of spores. Different fungicides act on different stages of the fungal lifecycle and not all fungicides are effective against all fungi. Resistance occurs when a pathogen that was once sensitive to a fungicide is no longer sensitive (not controlled). Managing the use of fungicides and fungicide resistance in production nurseries is important and can be achieved with planning. This factsheet provides a practical overview for nursery production managers to understand these topics and use fungicides effectively and responsibly.

Grow plants optimally to reduce the need to apply pesticides.

PROTECTANT, CURATIVE AND ERADICANT PRODUCTS

Fungicides are categorised by the stage of the disease cycle they target. Although the life cycles and biology of pathogens as a whole are very diverse, the disease cycle can be split into the following generalised stages:

- Infection (penetration of the host plant)
- Colonisation (multiplication of the pathogen within the local area of infection in the plant before symptoms occur)
- Symptom expression (visual signs of disease)
- Spore production and spread (normally occurs multiple times per year, depending upon the pathogen and environmental conditions)

A great deal of information on pesticides and their usage is available on the Nursery Production FMS website, including the Best practice manual for pesticide application and all current minor use permits for the production nursery industry.

Protectant or Preventative fungicides are often broad-spectrum products effective against a wide range of fungi. They act in the infection stage by providing a protective barrier that prevents infection.

Protectants are designed to be applied to healthy plant tissue to protect or prevent infection from taking place. They stay on the surface of the plant; they do not enter plant tissue. As such these products tend to have limited

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TABLE 1. FUNGICIDES REGISTERED AGAINST FOLIAR PATHOGENS IN PRODUCTION NURSERIES WITH ONLY PROTECTANT OR PREVENTATIVE ACTION.

MOA GROUP	ACTIVE INGREDIENTS
M1	Copper products
M2	Potassium bicarbonate, sulphur formulations
M3	Thiram, mancozeb
M5	Chlorothalonil

impact on colonisation, symptom development or spore production that take place after the pathogen is inside the plant. Where pathogens grow and sporulate on the surface of the plant (e.g. mildews, grey mould) these products can be very effective.

Many protectant products have multiple modes of action (e.g. M1, M2 etc.), which decreases the risk of inducing fungicide resistance. Repeated applications will be required leading up to and during periods of high disease pressure.

Curative or Penetrant fungicides act in the infection and early colonisation stages, before symptoms are visible. These products enter plant tissue and stop or reduce fungal growth; they can be translaminar (moving across the leaf from top to bottom) or systemic (move throughout the plant via the vascular tissues). Protection from fungal attack occurs within the plant cell, though they may also provide a protective barrier to reduce infection. They are more specific in their mode of action, generally only stopping fungal growth or development in one or a small number of ways. For this reason, these products may control a small number of diseases caused by closely related organisms. As a consequence, resistance is more likely to occur in these fungicides compared with protectant products.

They are best applied as soon after infection as possible (e.g. 1–3 days) as product efficacy decreases dramatically with time after infection. In other words, apply these products before symptoms are obvious and well before they are widespread. Repeated applications are normally required during periods of high pest pressure. Leaves produced after application are not protected and sporulation may still occur depending on the pathogen.

Despite the name, these products do not necessarily 'cure' plants.

TABLE 2. FUNGICIDES REGISTERED AGAINST FOLIAR PATHOGENS IN PRODUCTION NURSERIES WITH CURATIVE OR ERADICANT PROPERTIES

MOA GROUP[1]	ACTIVE INGREDIENTS	MOBILITY (CTS)[2]	ACTIVITY (PCE)[3]
1	Thiophanate methyl	S	P, C
2	Iprodione	C, T	P, some E/C
3	Prochloraz	T, S	P, C/E
3	Tebuconazole	T, S	P, C, E
4	Metalaxyl-M	S, C	P, C, E
7	Boscalid	T	P (some C)
7	Oxycarboxin	S	C
8	Bupirimate	T, S	P, C/E
9	Pyrimethanil	C, T	P (some C)
9	Cyprodonil	T/S	P, E/C
11	Azoxystrobin	C, S	P (some C)
11	Pyraclostrobin	T	P (some C)
11	Trifloxystrobin	T	P, C
12	Fludioxonil	C	P
21	Cyazofamid	C, T	P, E
28	Propamocarb	S	P, E/C
40	Dimethomorph	T	P, C, E

[1] The number represents the FRAC code which is the mode of action group on Australian fungicide labels

[2] C=contact, T=translaminar or locally systemic, S= systemic http://ipm.ucanr.edu/PMG/r302900211.html. Information presented here is based on current research. Knowledge of fungicide movement within plants can change as additional research becomes available. The T/S indicates that the mobility of the active ingredient is unclear.

[3] P= protectant, C= curative, E = eradicant. Where products are C/E it indicates that literature is unclear as to whether it is curative or eradicant or both.

Eradicant fungicides act on the later stages of colonisation (when symptoms are present) and can sometimes also act to suppress spore production. These products also stop or reduce fungal growth, which in turn stops or reduces disease development. Symptoms that have developed before the application will remain on plant tissue as long as it is present, e.g. leaf spots will remain on the leaf until it drops or is pruned out. Eradicant products are more likely to be systemic in action and may have some activity to new growth depending on the mobility of the product.

These products are very powerful for managing local fungal infections. However, they do not 'eradicate' fungal infections that are systemic within plants (e.g. vascular wilts and root rot pathogens). For this reason, fungicides are not recommended against plants infected with root rot and wilt pathogens in production nurseries. Similar to curative products, eradicants fungicides effect fungi in a specific way and are more at risk for inducing resistance.

Regardless of whether the product is a protectant, curative or eradicant fungicide, they are most effective when used early, before symptoms actually appear or when symptoms are very minor. Fungicide efficacy will vary with many conditions including the pathogen present, the host plant, the amount of time since infection and the amount of pathogen present in the growing area (the inoculum load). Efficacy will also vary with the concentration of the product and environmental conditions. It is not recommended to apply products when plants are heat stressed, when leaves are wet or when leaves are expected to become wet, e.g. through rain or irrigation. Fungicides may struggle to manage widespread diseases.

Fungicides will not eradicate soil-borne pathogens from growing media or pathogens present in plant vascular tissue (e.g. roots and main stems). Refer to the soil borne disease management plan for more information on the use of fungicides to manage these types of diseases.

Daphne infected with *Phytophthora nicotianae* should not be sold as they will always have the pathogen present, even if they appear healthy.

FUNGICIDE MODE OF ACTION GROUPS

All fungicides have a mode of action group as assigned by the Fungicide Resistance Action Committee (FRAC). Australia was the first country to legislate the requirement for the mode of action group to be printed on fungicide labels. Pre-2008 in Australia, the fungicide groups were allocated a letter only. Now, the mode of action group has been brought into line with the international standard. Australian fungicide labels have the FRAC code written on the label and is either a number or letter number combination. Each distinct number (or letter number combination) indicates that the fungicide stops the pathogen in a specific way, which is different from other codes. For example, azoxystrobin has the FRAC code 11 whereas tebuconazole has the FRAC code 3 (Table 2); their mode of action is different. Some countries do not use this system.

Understanding fungicide mode of action is complicated and requires a great deal of research to pinpoint. This is why some products are classified as group U, unknown mode of action. As new research becomes available, products may be moved from U to another mode of action group. However, sometimes information becomes available that makes a product be moved between mode of action groups.

FUNGICIDES AND BENEFICIAL INSECTS

Fungicides often have a very deleterious effect on predatory insects and mites. Some products may kill predators, parasites and pollinators outright. Other products may have non-lethal effects including a reduction in the number of eggs laid, reduced movement or reduced longevity. Repeated applications will increase negative effects, as will higher dosage. Refer to links in further reading for more information on side effects of fungicides.

Airblast sprayers can be efficient when applying fungicides to protect large areas of high-risk crop lines. Many spray units exist for different purposes. Photo by NGIQ.

Fungicides vary in the groups of fungi they affect; they are not effective against all fungal pathogens. Initial studies are normally conducted to determine the types of species or groups that are sensitive to the product; these are then put on the label. Some fungi will have an inherent or natural resistance or tolerance to the product, though the exact mechanism is rarely studied. While this is a type of resistance, it is not normally considered in detail.

Of greater importance is what is termed 'acquired resistance', where populations of a fungal pathogen that were once sensitive to a fungicide are no longer sensitive. As such, control is no longer achieved, sometimes dramatically so. Acquired resistance is a heritable trait that allows the fungus to survive an application of a particular fungicide. It generally occurs when products with a common physiological mechanism of action are used repeatedly, each time selecting for the resistant individuals, allowing them to eventually dominate a population.

Fungicide resistance is more likely to occur when the fungicide mode of action can be overcome by one inherited trait (e.g. most curative and eradicant products). In contrast, it is less likely to occur when the product has multiple modes of action. This is why fungi rarely develop resistance to products from the M mode of action group (protectants); individuals rarely occur that have all of the traits necessary to survive.

Fungicide resistance is a numbers game, although only one spore/strain may initially have the ability to escape the action of the fungicide, with repetitive application the resistant population can rapidly increase. Fungicide resistance can occur from a number of general mechanisms. The most common fungicide resistance mechanisms result from the fungus breaking down the fungicide or rendering it ineffective.

MANAGEMENT STRATEGIES TO REDUCE RESISTANCE

Various management strategies have been developed to reduce the incidence of fungicide resistance. Do not rely on any one of these strategies, implement as many as possible. Many products have a fungicide resistance management plan written on the label. Follow this strategy whenever it is available. When no resistance management plan is provided on the label the following guidelines can be used to reduce the likelihood of inducing fungicide resistance. More detailed information is available in the FRAC fungicide resistance monograph.

1. **Use cultural practices to reduce fungal populations and break the lifecycle of the pathogen**. Any action that keeps plants healthy and reduces the need to apply a fungicide will decrease the likelihood of inducing resistance. These actions are passive and perhaps the most important. Specific cultural practices that reduce disease pressure are discussed in many management plans and factsheets. In particular, avoid continuous plantings of susceptible crops, especially when they are showing symptoms. Reducing the number of treatments applied per crop drastically reduces the risk of inducing fungicide resistance.
2. **Only apply products when they are actually necessary**. Apply them when crop monitoring indicates that there is a need or when previous experience indicates that disease pressure is likely to be high.
3. **Apply to hot spots** as much as possible. Record susceptible crops and avoid applying pesticides to plants that do not require it.
4. **Apply protectant products leading up to high risk periods** on susceptible crop lines. Also note that certain fungal leaf pathogens can eventually become systemic vascular pathogens (e.g. downy mildew, *Pestalotiopsis* on some palm species). Once this occurs the plant cannot be cured and should be hygienically discarded. The disease should be managed early to reduce sporulation and ultimate crop loss. Large infestations generally require more applications to manage and may result in more genetic diversity, which may include a resistant variant.
5. **Limit the use of the eradicant and curative** fungicides to highest risk periods of the growing season where the pathogen could be most devastating. Disease pressure can also increase as the plants grow and become difficult to cover with protectant fungicides.
6. **Apply products with multiple mode of action groups**. It is recommended to apply products with different modes of action, either as a mixture or in rotation. If applying as a mixture ensure that fungicides are compatible. Fungicide incompatibility can occur for a variety of reasons that leads to a reduction in efficacy or an increase in phytotoxicity (see resources in further reading). There are an increasing number of products sold as a mixture of fungicides with multiple modes of action, often including a protectant and eradicant or curative product.
7. **Alternate fungicides with different modes of action**. This approach reduces the total number of applications of any given fungicide and therefore will reduce the risk of inducing fungicide resistance. As indicated above,

follow all fungicide resistance management strategies printed on the label, which may include limited sequential applications.

8. **Maintain the dose stated on the label**. Doses below the recommended rate may be ineffective at managing the pathogen, even at low pest pressure and therefore require more fungicide applications. Experimental and theoretical data on the effect of fungicide dosage on the risk of inducing fungicide resistance is complicated and not well understood.

The fungicide application did not work, is that resistance? Field observation is not conclusive proof. It may be a spray coverage or calibration problem, poor water quality, extreme weather conditions or a number of other factors. Testing for fungicide resistance requires detailed laboratory screening, which can be time consuming and expensive.

CONCLUSION

Fungicides are useful products that can play an important role in growing healthy nursery stock. Two Key points:

- Prevent the build-up of resistant individuals in the population by not overusing fungicides with a similar mode of action.
- Use an integrated strategy. Reduce the fungal population with cultural practices and avoid having a series of close plantings with the same crop.

Be targeted in fungicide use, choosing the best products to achieve the desired result. Remember that fungicides never truly eradicate pathogens; disease symptoms may disappear but the pathogen is likely to be present and able to re-emerge under favourable conditions.

WHY ARE FUNGICIDES INCREASINGLY EXPENSIVE?

New generation fungicides may cost $250 million AUD and may take over a decade or more to develop. This cost and investment into a new product is reflected in the retail price. As such, replacement of a fungicide lost to resistance can not be guaranteed; everyone must do their part to reduce the incidence of fungicide resistance.

FURTHER READING:

- For more information on fungicide resistance, resistance management and fungicide mode of action refer to the FRAC website and latest FRAC MOA poster.
- Active ingredient list, FRAC code and mode of action group factsheet.
- FRAC fungicide resistance monograph
- More specific information to Australian horticulture can be found at Croplife Australia.
- Leaf spots and fungicides webinar
- Australian production nursery industry pest and disease factsheets and pest management plans
- Fungicide compatibility testing information
- Production nursery industry's Best practice manual for pesticide application
- Side effects guidelines of fungicides on beneficial insects and mites are found at Biobest and Koppert.

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