Fungicide Resistance Management Strategies

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1. WHAT IS FUNGICIDE RESISTANCE?

Resistance by fungal pathogens to fungicides usually evolves following the intensive use of fungicides for disease control. In any fungal population there are likely to be individuals that have some degree of natural resistance and which are less susceptible to fungicides, even before the chemicals are used. Resistance arises through the incorrect use of fungicides by selection of the resistant forms of fungi. Continued use of a fungicide or fungicide chemical group can result in a significant build up of resistant individuals in the fungal population – to the point where that particular product, or other products from the same chemical group, is no longer effective. In some cases, removal of the selection pressure can result in the fungal population regaining its sensitivity to the fungicide group, but this is not always the case. The risk of fungicide resistance developing varies between different chemical groups and different fungal pathogens, such that specific strategies are recommended for those situations considered to carry the highest risk.

2. WHAT CAN BE DONE TO PREVENT OR DELAY RESISTANCE?

2.1 The most common approach to managing fungicide resistance is through responsible use of fungicides, of which the resistance management strategies presented in this document are good examples. In their most basic form, these strategies advocate rotation of fungicide products with a different chemical activity group to prevent over-use of any one product or activity group. More complex strategies safeguard against the development of cross-resistance or resistance to multiple chemical groups. All fungicide products are labelled to identify which activity group they belong to. The activity group is indicated by a number (or letter/number combination) code on the product label.

2. WHAT CAN BE DONE TO PREVENT OR DELAY RESISTANCE?

2.2 Selecting the most effective or appropriate way to apply fungicides will make them work better and assist in delaying the development of resistance. A good understanding of the pathogen's life cycle and epidemiology will also help in the selection of the most appropriate application method. As a general rule, targeted applications to control a certain development stage or population level are most effective, whereas shotgun approaches like application of fungicides through irrigation systems could accelerate the development of resistance by exposing a large portion of the fungal population to sub-lethal rates. Particular attention should be given to label recommendations, rates and coverage. Adherence to suggested disease threshold levels is also good resistance management practice.

2. WHAT CAN BE DONE TO PREVENT OR DELAY RESISTANCE?

2.3 The use of cultural practices or growing varieties of crops with a high degree of natural resistance to diseases – requiring fewer or less frequent fungicide applications.

2.4 Working with industry bodies to establish resistance management strategies for minor crops and/or those crops for which no strategies exist. Of particular concern are permitted uses of fungicides, often in minor crops, where repeated use of a limited number of fungicide alternatives occurs. Although not explicitly stated on agricultural use permits, such permitted uses should also incorporate measures to prevent resistance.

2.5 In the event of tank mixing products and/or co-formulations, always follow the recommendation from the most recent Fungicide Resistance Management Strategies and apply the apply the most stringent strategy applicable to the pathogen most at risk of developing resistance.

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2.6 Certain environments are conducive to continuous infection and consistently high disease pressure. Examples of such environments are nurseries, tunnels, glasshouses and other structures of protected cultivation. Because protected cultivation usually requires multiple applications of fungicides at short intervals to control high disease incidence, these are often the origin of resistance to fungicides. Users of fungicides should be particularly mindful of the resistance risk under these conditions. Do not use a fungicide product to which resistance has been confirmed and stop using a product if resistance is suspected. When the fungicide in question no longer gives adequate control, stop using it temporarily and consult the supplier on its current resistance status.

2. WHAT CAN BE DONE TO PREVENT OR DELAY RESISTANCE?

2.7 In the absence of an established resistance management strategy for a particular crop/disease situation, it is recommended that the use of fungicides from any given activity group (excluding Group M) be limited to a maximum of one-third of the total number of fungicide applications. The use of consecutive applications of fungicides from the same activity group should also be limited by alternating between products from different activity groups. The use of Group M fungicides is not limited, as these fungicides carry an inherently low risk of fungicide resistance developing

Resistance Management Strategies for Crops

Apples & Pears

Fruit : post-harvest treatment

Stone Fruit

Grape

Potato

Tomato

CropLife SOUTH AFRICA

Crop(s): Apples, Pears
Pest(s): Apple and Pear Scab

Resistance Management Strategy for:

Group 3 (DMI);

Group 9 (Anilinopyrimidine);

Group 11 (Quinone outside Inhibitor) fungicides; and

Combinations of Group 9 (Anilinopyrimidine) and Group **3** (DMI) fungicides; and Dodine.

1. To prevent or delay the onset of resistance to Group **3** fungicides, **DO NOT** apply more than four **Group 3** sprays alone per season. If more sprays, are required apply a tank mix of a **Group 3** with a **Group 9** or suitable product from **Groups M** or **M1** to **M9**, or apply a registered product containing a combination of a **Group 3** and a **Group 9** fungicide.
2. **DO NOT** apply more than four sprays per season of **Group 9** fungicides (solo products).

   DO NOT apply more than five sprays per season of products containing a combination of a **Group 9** and a **Group 3** fungicide.

   DO NOT apply more than three sprays per season of **Group 11** fungicides. If two or three consecutive applications of **Group 11** fungicides are used, then they must be followed by at least the same number of applications of fungicide(s) from a different group(s) before a **Group 11** fungicide is used again, either in the current or following season.

   Where spray programs include both solo **Group 9** products and combination products, the maximum cumulative number of applications is five per season.
3. To prevent or delay the onset of resistance to Dodine, **DO NOT** apply more than three consecutive sprays of Dodine, and no more than a total of six Dodine sprays per season.

   If more sprays are required, tank mix Dodine with a protectant product at the registered rate.

CropLife SOUTH AFRICA

Crop(s): Fruit (post-harvest treatment)
Pest(s): Post-harvest diseases

Resistance Management Strategy for:

Group 3 (DMI);

Group 2 (Dicarboximide); and other “systemic” fungicides; and

Group 12 (Phenylpyrroles) fungicides

1. For the last pre-harvest spray, use a fungicide with a different activity group to the fungicide planned for use as a post-harvest treatment.
2. Where alternatives are available, rotate to use as many different activity groups as possible.
3. **DO NOT** dispose of unused dip solutions as a spray to crops or orchards.
4. **DO NOT** dispose of unused dip solutions within or near the crop or orchard area.

CropLife SOUTH AFRICA

Crop(s): Stone Fruit
Pest(s): Blossom Blight and Brown Rot

Resistance Management Strategy for:

Group 3 (DMI);

Group 2 (Dicarboximide); and

Group 9 (Anilinopyrimidine) fungicides

1. If applying **Group 2** or **3** fungicides, **DO NOT** apply more than two consecutive sprays of fungicides from the same group before changing to another group.
2. **DO NOT** apply more than three sprays of a **Group 9** fungicide per season. If two or three consecutive sprays are applied, they must be followed by at least the same number of sprays from an alternative chemical group, including from one season to the next.
3. A post-harvest treatment should also be counted as an application.
4. The last blossom blight spray and the first pre-harvest brown rot spray should be regarded as consecutive applications.
5. The spray program should be considered and the strategy applied on a whole-orchard basis.

CropLife SOUTH AFRICA

Crop(s): Grape
Pest(s): Downy Mildew

Resistance Management Strategy for:

Group 4 (Phenylamide);

Group 11 (Quinone outside Inhibitor); and

Group 40 (**C**arboxylic **A**cid **A**mides (**CAA**)) fungicides

1. Start disease control sprays when the vine shoots are approximately 20cm long and continue spraying at intervals of 7-21 days using a protectant or non-phenylamide fungicide.
2. When conditions favour disease development, apply two consecutive sprays of a **Group 4** product. **DO NOT** apply more than two consecutive sprays of a **Group 4** product. **DO NOT** apply more than four sprays of a **Group 4** product per season.
3. **DO NOT** apply more than three consecutive sprays of a **Group 40** fungicide, and no more than a total of six sprays per season.
4. **DO NOT** apply more than two sprays per season of **Group 11** fungicides. If two consecutive applications of **Group 11** fungicides are used, then they must be followed by at least the same number of applications of fungicide(s) from a different group(s) before a **Group 11** fungicide is used again, either in the current or following season.
5. Apply **Group 11** fungicides preventatively.
6. Apply a maximum of two consecutive applications in alternation with fungicides from a different MOA group with satisfactory efficacy against the target pathogen/s.

CropLife SOUTH AFRICA

Crop(s): Grape
Pest(s): Powdery Mildew

Resistance Management Strategy for:

Group 3 (DMI);

Group 5 (Amine);

Group 7 (SDI; carboxamides);

Group 11 (Quinone outside Inhibitor);

Group 13 (Quinoline) fungicides; and

Group U8 (Actin Inhibitor) fungicides

1. **DO NOT** apply more than two consecutive sprays of a **Group 3** fungicide.

   DO NOT apply more than three **Group 3** sprays per season.

   DO NOT use **Group 3** fungicides curatively.
2. **DO NOT** apply more than two consecutive sprays of a **Group 5** fungicide.

   DO NOT apply more than three **Group 5** sprays per season.
3. **DO NOT** apply consecutive sprays of **Group 7** fungicides, including from the end of one season to the start of the following season

   DO NOT apply more than four **Group 7** sprays per season.
4. **DO NOT** apply more than two sprays per season of **Group 11** fungicides. If two consecutive applications of **Group 11** fungicides are used, then they must be alternated with a fungicide from a different activity group.
5. Apply **Group 11** fungicides preventatively.
6. Apply a maximum of two consecutive applications in alternation with fungicides from a different MOA group with satisfactory efficacy against the target pathogen/s.
7. **DO NOT** apply more than two consecutive sprays of a **Group 13 f**ungicide.

   DO NOT apply more than three **Group 13** sprays per **seaso**n**.**

CropLife SOUTH AFRICA

Crop(s): Grape
Pest(s): Grey Mould (Bunch Rot)

Resistance Management Strategy for:

Group 2 (Dicarboximide);

Group 9 (Anilinopyrimidine) and combinations of **Group 9** (Anilinopyrimidine) and **Group 12** (Phenylpyrroles);

Group 17 (Hydroxyanilide); and

Group 7 (SDI; carboxamide) fungicides

1. If three or fewer bunch rot sprays are applied in a season, use no more than one spray from the same fungicide group during the season, for any **Group 2** or **9** (including combinations with **Group 12**), **Group 17** or **7** fungicides.
2. If four or more bunch rot sprays are applied in a season, use no more than two sprays from the same fungicide group during the season, for any **Group 2** or **9** (including combinations with **Group 12**), **Group 17** or **7** fungicides.
3. **DO NOT** apply more than two consecutive sprays from the same fungicide group, for any **Group 2** or **9** (including combinations with **Group 12**) or **Group 17** fungicide, including from the end of one season to the start of the following season.
4. **DO NOT** apply consecutive sprays of **Group 7** fungicides, including from the end of one season to the start of the following season.
5. Late season fungicide treatments should be applied before Botrytis infection reaches unacceptably high levels in the vineyard

CropLife SOUTH AFRICA

Crop(s): Potato
Pest(s): Late Blight

Resistance Management Strategy for:

Group 4 (Phenylamide);

Group 11 (Quinone outside Inhibitor); and

Group 40 (**C**arboxylic **A**cid **A**mides (**CAA**)) fungicides

1. Start disease control early and maintain a regular program using a fungicide from groups other than **Group 4**, **11** or **40**.
2. When conditions favour disease development, **DO NOT** wait for disease to appear, but apply two consecutive sprays of a **Group 4**, **11** or **40** fungicide at the interval recommended on the label. Then resume the program of sprays using products from a different group to the **Group 4**, **11** or **40** fungicides just applied.
3. **DO NOT** apply more than four sprays of a **Group 4** or **40** fungicide per season.
4. The total number of **Group 11** fungicide applications per season should not exceed one third of the total number of fungicide applications per crop. No more than two consecutive **Group 11** sprays should be applied. If consecutive applications of **Group 11** fungicides are used, then they must be followed by at least the same number of applications of fungicide(s) from a different group(s) before a **Group 11** fungicide is used again, either in the current or following season.

CropLife SOUTH AFRICA

Crop(s): Potato
Pest(s): Early Blight

Resistance Management Strategy for:

Group 2 (Dicarboximide);

Group 3 (DMI);

Group 7 (SBI; carboxamide) ;

Group 9 (Anilinopyrimidine); and

Group 11 (Quinone outside Inhibitor) fungicides.

1. Limit the use of **Group 2**, **3, 9** or **11** fungicides to periods when conditions favour disease development.
2. **DO NOT** apply more than six **Group 2** sprays in one season. Apply no more than two consecutive sprays of a **Group 2** fungicide.
3. **DO NOT** apply more than six **Group 3** sprays in a season. Apply no more than two consecutive sprays of a **Group 3** fungicide alone.
4. **DO NOT** apply more than four **Group 7** sprays per season. Always tank mix **Group 7** fungicides with a protectant such as mancozeb or metiram.
5. If three or fewer fungicide sprays for target spot are applied per crop, use only one spray containing a **Group 9** fungicide. If four to six sprays are applied per crop, use a maximum of two sprays containing **Group 9** fungicides. If seven or more sprays are applied per crop use a maximum of three sprays containing **Group 9** fungicides.

   Apply no more than two consecutive sprays containing a **Group 9** fungicide.
6. Apply **Group 11** fungicides preventively. **DO NOT** apply more than three foliar applications of a **Group 11** fungicide per crop, no more than two consecutive **Group 11** sprays per crop. If consecutive applications of **Group 11** fungicides are used, then they must be followed by at least the same number of applications of fungicide(s) from a different group(s) before a **Group 11** fungicide is used again, either in the current or following season.
7. When using a Group 11 fungicide in-furrow at planting, use a fungicide from a different group as the first foliar spray.

CropLife SOUTH AFRICA

Crop(s): Tomato
Pest(s): Grey Mould

Resistance Management Strategy for:

Group 2 (Dicarboximide) fungicides

1. Tank mix **Group 2** fungicides with a protectant such as chlorothalonil, or with each other. Avoid applying two **Group 2** fungicides in succession, unless tank mixed with a protectant.

2. **DO NOT** apply more than four **Group 2** sprays in a season.

CropLife SOUTH AFRICA

Crop(s): Tomato
Pest(s): Early Blight

Resistance Management Strategy for:

Group 2 (Dicarboximide);

Group 3 (DMI);

Group 7 (SDI, carboxamide) ;

Group 9 (Anilinopyrimidine); and

Group 11 (Quinone outside Inhibitor) fungicides

1. Limit the use of **Group 2**, **3**, **9** or **11** fungicides to periods when conditions favour disease development.
2. **DO NOT** apply more than four **Group 2** sprays in one season. Apply no more than two consecutive sprays of a **Group 2** fungicide.
3. **DO NOT** apply more than six **Group 3** sprays in a season. Apply no more than two consecutive sprays of a **Group 3** fungicide alone.
4. **DO NOT** apply more than four **Group 7** sprays in a season. Always tank mix **Group 7** fungicides with a protectant such as mancozeb or metiram.
5. If three or fewer fungicide sprays for target spot are applied per crop, use only one spray containing a **Group 9** fungicide. If four to six sprays are applied per crop, use a maximum of two sprays containing **Group 9** fungicides. If seven or more sprays are applied per crop, use a maximum of three sprays containing **Group 9** fungicides.

   Apply no more than two consecutive sprays containing a **Group 9** fungicide.
6. Apply **Group 11** fungicides preventatively. **DO NOT** apply more than six sprays, or one third of total sprays (whichever is lower) from **Group 11** fungicides. **DO NOT** apply more than two consecutive sprays of **Group 11** fungicides. If consecutive applications of **Group 11** fungicides are used, then they must be followed by at least the same number of applications of fungicide(s) from a different group(s) before a **Group 11** fungicide is used again, either in the current or following season.

CropLife SOUTH AFRICA

FRAC Code No. 9 : **A**nilino**P**yrimidines (**AP**'s)

CODE	TARGET SITE OF ACTION	GROUP NAME	CHEMICAL GROUP	COMMON NAME	COMMENTS
9	methionine biosynthesis (cgs gene, proposed)	**AP** - fungicides (**A**nilino-**P**yrimidines)	anilino-pyrimidines	cyprodinil mepanipyrim pyrimethanil	Resistance known in Botrytis and Venturia, sporadically in Oculimacula. Medium risk See FRAC Anilinopyrimidine guidelines for resistance management

CropLife SOUTH AFRICA

FRAC Code No. 40 : **C**arboxylic **A**cid **A**mides (**CAA**)

CODE	TARGET SITE OF ACTION	GROUP NAME	CHEMICAL GROUP	COMMON NAME	COMMENTS
40	Cellulose synthesis (updated Jan. 2011)	**CAA** -fungicides (**C**arboxylic **a**cid **a**mides)	cinnamic acid amides	dimethomorph flumorph	Low to medium risk. Resistance management required.
			valinamide carbamates	benthiavalicarb iprovalicarb valifenalate	
			mandelic acid amides	mandipropamid	

CropLife SOUTH AFRICA

Sterol Biosynthesis Inhibitors (SBI's)

Sterol Biosynthesis Inhibitors				
SBI Class: FRAC serial code FRAC target no.	**I** **3** **G1**	**II** **5** **G2**	**III** **17** **G3**	**IV** **18** **G4**
Group name	**De-Methylation Inhibitors: (DMI**s)	amines (formerly 'morpholines')	hydroxy-anilides	squalene-epoxidase inhibitors
Target in Sterol Biosynthesis	sterol C14 demethylase	Δ^{14} reductase and $\Delta^{7} \rightarrow \Delta^{8}$ isomerase	3-keto reductase	squalene-epoxidase
Chemistry	piperazines pyridines pyrimidines imidazoles triazoles	morpholines piperidines spiroketalamines	hydroxyanilides	thiocarbamates [1] allylamines [2]
Uses	agriculture (fungicide) material protection medicine (antimycotic)	agriculture (fungicide)	agriculture (fungicide)	agriculture (herbicide) [1] medicine [2] (antimycotic)

CropLife SOUTH AFRICA

FRAC Code No. 7 : **S**uccinate **D**ehydrogenase **I**nhibitor

CODE	TARGET SITE OF ACTION	GROUP NAME	CHEMICAL GROUP	COMMON NAME	COMMENTS
7	Complex II; succinate-dehydrogenase		Phenyl-benzamides	Benodanil Flutolanil Mepronil	Resistance known for several fungal species in field populations and lab mutants. Target site mutations in sdh gene, e.g. H/Y (or H/L) at 257, 267, 272 or P225L. Medium-high risk. Resistance management required
			Pyridinyl-ethyl-benzamide	Fluopyram	
			Furan-carboxamides	Fenfuram	
			Oxathiin-carboxamides	Carboxin Oxycarboxin	
			Thiazole-carboxamides	Thifluzamide	
			Pyrazole-carboxamides	Bixafen Fluxapyroxad Furametpyr Isopyrazam Penflufen Penthiopyrad Sedaxane	
			Pyridine-carboxamides	Boscalid	

CropLife SOUTH AFRICA

FRAC Code No. 11 - QoI fungicides :

GROUP NAME	CHEMICAL GROUP	COMMON NAME	COMMENTS	FRAC CODE
QoI-fungicides (**Q**uinone **o**utside **I**nhibitors)	methoxy-acrylates	azoxystrobin coumoxystrobin enoxastrobin flufenoxystrobin picoxystrobin pyraoxystrobin	Resistance known in various fungal species. Target site mutations in cyt b gene (G143A, F129L) and additional mechanisms. Cross resistance shown between all members of the QoI group. **High risk.** **See FRAC QoI Guidelines for resistance management.**	11
	methoxy-carbamates	pyraclostrobin pyrametostrobin triclopyricarb		
	oximino acetates	kresoxim-methyl trifloxystrobin		
	oximino-acetamides	dimoxystrobin fenaminostrobin metominostrobin orysastrobin		
	oxazolidine-diones	famoxadone		
	dihydro-dioxazines	fluoxastrobin		
	Imidazolinones	fenamidone		
	benzyl-carbamates	pyribencarb		

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