CFAES

Fungicide Resistance Management-Best Practices

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2020 Grape Winter School

1

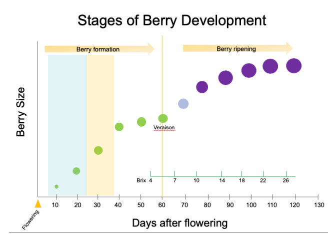
Fungicides are an Integral Part of a Disease Management Program

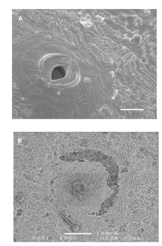
2

Fungicides Applied to Protect Clusters

- Prevent the build up of inoculum in the vineyard

3





Stomate on berries close and are sealed with waxy cuticle

Age-related Resistance Protects the Berries

- Berries are resistant to new infections three to five weeks post bloom depending on the variety

4

Critical Period For Disease Control of Clusters

- Infections occur at night when temperatures are between 64-76 F

5

Spray No.	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Growth Stage	Dormant	Bud Break	1 inch	3-5 inch	6-9 inch	10-12 inch	Pre-bloom to early bloom	Pre-bloom to early bloom	(1st post-bloom)	Pea-size (2nd post-bloom)	Pea-size (3rd post-bloom)	Berry Touch (4th post-bloom)	Berry Touch (5th post-bloom)	Veraison	Pre-harvest
	Anthracnose		Phomopsis									Botrytis Bunch Rot			
	Sulforix		Mancozeb (M)	Mancozeb (M)	Mancozeb (M)	Mancozeb (M)						Vangard (9)	Vangard (9)	Endura (7)	
				Powdery Mildew											
				Stylet Oil	Sulfur (M) or LifeGard	Sulfur (M) or LifeGard	Revus Top (40+3)	Inspire Super (3+9)	Pristine (7+11) or Sulfur (M)	Quintec (13)	Torino (U6)	Quintec (13) or LifeGard	Torino (U6)	Vivand (U8) or LifeGard	Potassium salts
				Downy Mildew											
				Mancozeb (M)	Mancozeb (M)	Mancozeb (M)	Revus Top (40+3)	Zampro (45+40)	Pristine (7+11)	Captan (M) or Mancozeb (M)	Captan (M) or Mancozeb (M)	Captan (M)	Captan (M)	Captan (M)	Potassium salts or Revus (40)
						Black Rot									
						Mancozeb (M)	Revus Top (40+3)	Inspire Super (3+9)	Pristine (7+11)	Captan (M) or Mancozeb (M)	Captan (M) or Mancozeb (M)				
							Critical Period								

Critical Period for Fungicide Applications

- During this time you must protect the clusters from infections

6

Risk Factors Contributing to Resistance development

- Factors associated with the fungicide
  - Fungicide mobility
  - Fungicide mode of action
  - Fungicide use patterns
- Factors associated with the fungus
  - Fungus biology
  - Fitness of fungicide resistant fungal isolates
- Crop production practices

7

Fungicide Mobility

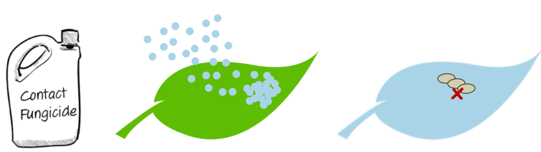
Can not penetrate into the plant

Can penetrate and protect short distances in the plant

Can penetrate and protect whole plant (including new tissue)

8

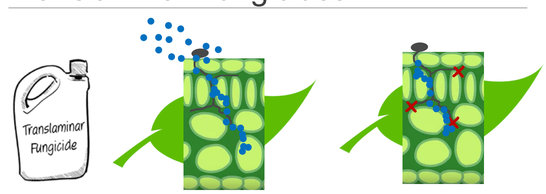
Non-systemic (Contact) Fungicides



- Applied BEFORE the fungus (spores) arrives
- Prevents fungus germination and penetration

9

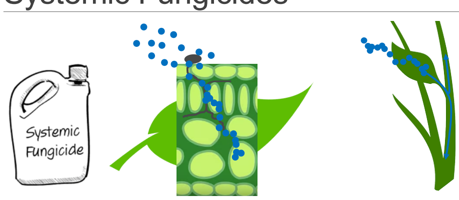
Translaminar Fungicides



- Locally systemic
- Penetrates plant tissue
- Kills fungus that has infected plant tissue

10

Systemic Fungicides



- Penetrates plant tissue
- Moves through the entire plant and protects new tissue

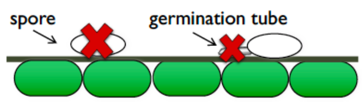
11

Physical Mode of Action

12

Protectant

- Act as a chemical barrier
- Kills fungal spores on the plant surface
- Inhibits spore germination or penetration
- Effective coverage is critical

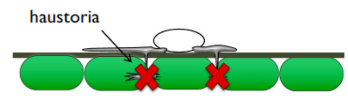


- Sulfur
- Copper
- Captan
- Mancozeb
- Oils
- Quintec

13

Curative

- Locally systemic
- Inhibits further growth of the pathogen after infection has occurred
- Timing of infection periods is critical
- Effectiveness expressed as "kick-back" activity



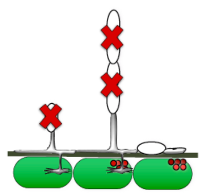
Fungicide	Kick-back Activity (h)
Elevate	48
Sovran	48-72
Rubigan	72-96

- Vivando (metrafenone)
- Endura (boscalid)
- Rubigan (fenarimol)
- Elevate (fenhexamid)
- Torino (cyflufenamid)
- Flint (trifloxystrobin)

14

Antisporulant

- Systemic movement
- Prevents or reduces sporulation on active lesions



- Rally (myclobutanil)
- Procure (triflumizole)
- Orius (tebuconazole)
- Mettle (tetraconazole)
- Abound (azoxystrobin)
- Pristine (pyraclostrobin)

15

Biochemical Mode of Action

16

Single Site vs Multi Site Activity

SINGLE SITE

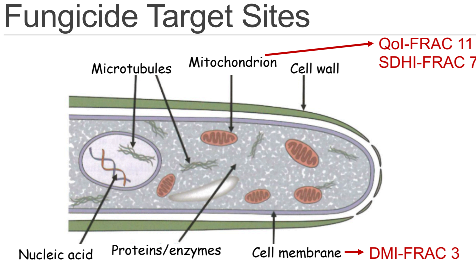
- Acts on a specific target site within the fungus
- Generally systemic fungicides
- Single or multiple genes affected
- Moderate to high risk for resistance development

MULTI SITE

- Acts on multiple sites within the fungus
- Generally contact (protectant) fungicides
- Multiple genes affected
- Low risk for resistance development

17

Fungicide Target Sites



18

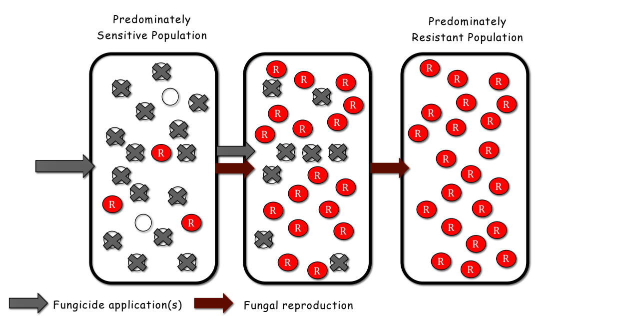
FRAC	Mode of Action	Active Ingredient	Commercial Product
2	Signal transduction	iprodione	Rovral
3	Sterol biosynthesis in membranes (DMI)	fenarimol, myclobutanil, tetraconazole, difenconazole, tebuconazole	Rubigan, Rally, Mettle, Revus Top; Quadris Top*, Fervent, Luna Experience, Adament
7	Complex II Respiration (succinate dehydrogenase) (SDHI)	boscalid, fluopyram, benzovindiflupyr, isofetamid	Endura, Pristine, Luna Experience, Aprovia, isofetamid Fervent*, Isofetamid 400, Kenja 400SC
11	Complex III Respiration (ubiquinol oxidase) (QoI)	azoxystrobin, kresoxim-methyl, trifloxystrobin, pyraclostrobin	Quadris Top, Abound, Sovran, Flint, Adamant, Pristine*
13	Signal transduction (mechanism unknown)	quinoxyfen	Quintec
50	Cytoskeleton – actin / myosin function	metrafenone, pyriofenone	Vivando, Prolivo
M	Multi-site	Copper, sulfur	Sulfur dust, Sulforix, Bordeaux mix
U	Unknown	cyflufenamid	Torino, Miltrex

19

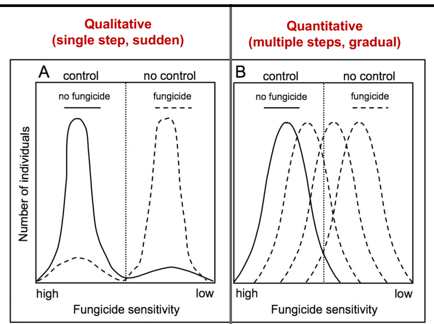
Fungicide Resistance

- Genetic change in the fungus that leads to reduced sensitivity to a fungicide
- Stable, heritable trait
- Governed by a single gene or multiple genes
- Occurs when there is a shift in the fungal population from predominately sensitive isolates to predominately resistant isolates

20



21



22

Types of Resistance

- Cross-resistance
  - Resistance arises to one fungicide that also results in resistance to another fungicide
  - Occurs with fungicides with the same site-specific mode of action
  - Does not require exposure to both fungicides
- Negative cross-resistance
  - A change results in a reduction in sensitivity to one fungicide and an increase in sensitivity to another fungicide (rare)
- Multiple resistance
  - Resistance to two or more fungicidal modes of action

23

Risk Factors Contributing to Resistance development

- Factors associated with the fungus
  - Fungus biology
  - Fitness of fungicide resistant fungal isolates
- Factors associated with the fungicide
  - Fungicide mobility
  - Fungicide mode of action
  - Fungicide use patterns
- Crop production practices

24

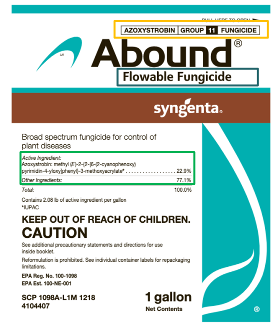
The Fungicide Label

- Contains all the information about the fungicide that you are required to know by law
  - Hazards to humans, animals, environment
  - Agricultural use requirements (PHI, REI, maximum seasonal use, etc.)
  - Storage and disposal
  - Tank mix compatibility
  - Spraying and mixing instructions
  - Management (resistance and drift)

The Label is the Law

25

Reading the Label



Active ingredient and FRAC Group

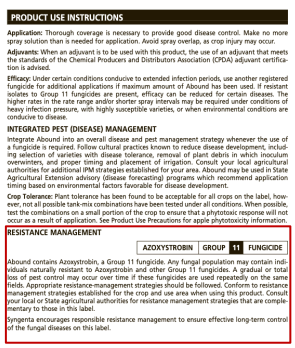
Formulation

Active and inert ingredients

26

Resistance Management

- Recommendations for integrated disease management best practices and resistance management



PRODUCT USE INSTRUCTIONS

Application: Thorough coverage is necessary to provide good disease control. Make no more spray solution than is needed for application. Avoid spray overlap, as crop injury may occur.

Adjuvants: When an adjuvant is to be used with this product, the use of an adjuvant that meets the standards of the Chemical Producers and Distributors Association (CPDA) adjuvant certification is advised.

Efficacy: Under certain conditions conducive to extended infection periods, use another registered fungicide for additional applications if maximum amount of Abound has been used. If resistant isolates to Group 11 fungicides are present, efficacy can be reduced for certain diseases. The higher rates in the rate range and/or shorter spray intervals may be required under conditions of heavy infection pressure, with highly susceptible varieties, or when environmental conditions are conducive to disease.

INTEGRATED PEST (DISEASE) MANAGEMENT

Integrate Abound into an overall disease and pest management strategy whenever the use of a fungicide is required. Follow cultural practices known to reduce disease development, including selection of varieties with disease tolerance, removal of plant debris in which inoculum overwinters, and proper timing and placement of irrigation. Consult your local agricultural authorities for additional IPM strategies established for your area. Abound may be used in State Agricultural Extension advisory (disease forecasting) programs which recommend application timing based on environmental factors favorable for disease development.

Crop Tolerance: Plant tolerance has been found to be acceptable for all crops on the label, however, not all possible tank-mix combinations have been tested under all conditions. When possible, test the combinations on a small portion of the crop to ensure that a phytotoxic response will not occur as a result of application. See Product Use Precautions for apple phytotoxicity information.

RESISTANCE MANAGEMENT

AZOXYSTROBIN | GROUP 11 | FUNGICIDE

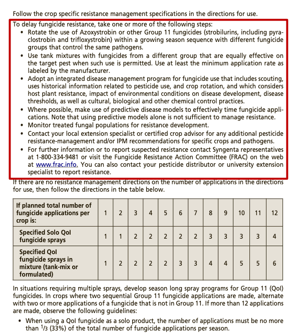
Abound contains Azoxystrobin, a Group 11 fungicide. Any fungal population may contain individuals naturally resistant to Azoxystrobin and other Group 11 fungicides. A gradual or total loss of pest control may occur over time if these fungicides are used repeatedly on the same fields. Appropriate resistance-management strategies should be followed. Conform to resistance management strategies established for the crop and use area when using this product. Consult your local or State agricultural authorities for resistance management strategies that are complementary to those in this label.

Syngenta encourages responsible resistance management to ensure effective long-term control of the fungal diseases on this label.

27

Resistance Management

- Best practices to reduce the rate of resistance development are provided in the label



Follow the crop specific resistance management specifications in the directions for use.

To delay fungicide resistance, take one or more of the following steps:

- Rotate the use of Azoxystrobin or other Group 11 fungicides (strobilurins, including pyraclostrobin and trifloxystrobin) within a growing season sequence with different fungicide groups that control the same pathogens.
- Use tank mixtures with fungicides from a different group that are equally effective on the target pest when such use is permitted. Use at least the minimum application rate as labeled by the manufacturer.
- Adopt an integrated disease management program for fungicide use that includes scouting, uses historical information related to pesticide use, and crop rotation, and which considers host plant resistance, impact of environmental conditions on disease development, disease thresholds, as well as cultural, biological and other chemical control practices.
- Where possible, make use of predictive disease models to effectively time fungicide applications. Note that using predictive models alone is not sufficient to manage resistance.
- Monitor treated fungal populations for resistance development.
- Contact your local extension specialist or certified crop advisor for any additional pesticide resistance-management and/or IPM recommendations for specific crops and pathogens.
- For further information or to report suspected resistance contact Syngenta representatives at 1-800-334-9481 or visit the Fungicide Resistance Action Committee (FRAC) on the web at www.frac.info. You can also contact your pesticide distributor or university extension specialist to report resistance.

If there are no resistance management directions on the number of applications in the directions for use, then follow the directions in the table below.

If planned total number of fungicide applications per crop is:	1	2	3	4	5	6	7	8	9	10	11	12
Specified Solo QoI fungicide sprays	1	1	2	2	2	2	2	3	3	3	3	4
Specified QoI fungicide sprays in mixture (tank-mix or formulated)	1	2	2	2	2	3	3	4	4	5	5	6

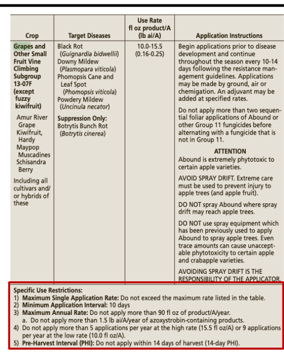
In situations requiring multiple sprays, develop season long spray programs for Group 11 (QoI) fungicides. In crops where two sequential Group 11 fungicide applications are made, alternate with two or more applications of a fungicide that is not in Group 11. If more than 12 applications are made, observe the following guidelines:

- When using a QoI fungicide as a solo product, the number of applications must be no more than 1/3 (33%) of the total number of fungicide applications per season.

28

Use Restrictions

- Specific use instructions vary depending on the crop



Crop	Target Diseases	Use Rate fl oz product/A (lb ai/A)	Application Instructions
Grapes and Other Small Fruit Vine Climbing Subgroup 13-07F (except fuzzy kiwifruit) Amur River Grape Kiwifruit, Hardy Maypop Muscadines Schisandra Berry Including all cultivars and/or hybrids of these	Black Rot (*Guignardia bidwellii*) Downy Mildew (*Plasmopara viticola*) Phomopsis Cane and Leaf Spot (*Phomopsis viticola*) Powdery Mildew (*Uncinula necator*) **Suppression Only:** Botrytis Bunch Rot (*Botrytis cinerea*)	10.0-15.5 (0.16-0.25)	Begin applications prior to disease development and continue throughout the season every 10-14 days following the resistance management guidelines. Applications may be made by ground, air or chemigation. An adjuvant may be added at specified rates. Do not apply more than two sequential foliar applications of Abound or other Group 11 fungicides before alternating with a fungicide that is not in Group 11. **ATTENTION** Abound is extremely phytotoxic to certain apple varieties. AVOID SPRAY DRIFT. Extreme care must be used to prevent injury to apple trees (and apple fruit). DO NOT spray Abound where spray drift may reach apple trees. DO NOT use spray equipment which has been previously used to apply Abound to spray apple trees. Even trace amounts can cause unacceptable phytotoxicity to certain apple and crabapple varieties. AVOIDING SPRAY DRIFT IS THE RESPONSIBILITY OF THE APPLICATOR.

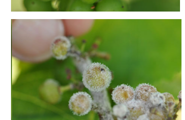
Specific Use Restrictions:

1) **Maximum Single Application Rate:** Do not exceed the maximum rate listed in the table.
2) **Minimum Application Interval:** 10 days
3) **Maximum Annual Rate:** Do not apply more than 90 fl oz of product/A/year.
   a. Do not apply more than 1.5 lb ai/A/year of azoxystrobin-containing products.
4) Do not apply more than 5 applications per year at the high rate (15.5 fl oz/A) or 9 applications per year at the low rate (10.0 fl oz/A).
5) **Pre-Harvest Interval (PHI):** Do not apply within 14 days of harvest (14-day PHI).

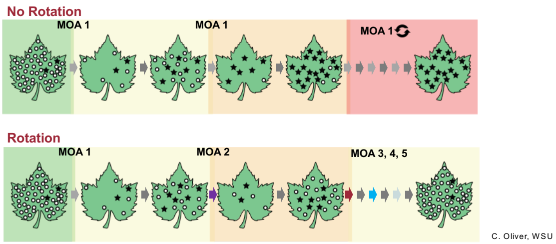
29

Fungicide Resistance Management Strategies

- Strategies that delay resistance development in the fungal population
  - Accurate and rapid disease diagnosis
  - Integration of management strategies
  - Selection of the correct fungicide
  - Targeted spray applications
  - Fungicide stewardship
    - Multiple modes of action
    - Multiple use patterns



30



1. ROTATE MODES OF ACTION

- Use protectant fungicides as much as possible
- Tank-mix protectant fungicides with systemic fungicides

31

Spray No.	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Growth Stage	Dormant	Bud Break	1 inch	3-5 inch	6-9 inch	10-12 inch	Pre-bloom to early bloom	Pre-bloom to early bloom	(1st post-bloom)	Pea-size (2nd post-bloom)	Pea-size (3rd post-bloom)	Berry Touch (4th post-bloom)	Berry Touch (5th post-bloom)	Veraison	Pre-harvest
	Anthracnose		Phomopsis									Botrytis Bunch Rot			
	Sulforix		Mancozeb (M)	Mancozeb (M)	Mancozeb (M)	Mancozeb (M)						Vangard (9)	Vangard (9)	Endura (7)	
				Powdery Mildew											
				Stylet Oil	Sulfur (M) or LifeGard	Sulfur (M) or LifeGard	Revus Top (40+3)	Inspire Super (3+9)	Pristine (7+11) or Sulfur (M)	Quintec (13)	Torino (U6)	Quintec (13) or LifeGard	Torino (U6)	Vivand (U8) or LifeGard	Potassium salts
				Downy Mildew											
				Mancozeb (M)	Mancozeb (M)	Mancozeb (M)	Revus Top (40+3)	Zampro (45+40)	Pristine (7+11)	Captan (M) or Mancozeb (M)	Captan (M) or Mancozeb (M)	Captan (M)	Captan (M)	Captan (M)	Potassium salts or Revus (40)
						Black Rot									
						Mancozeb (M)	Revus Top (40+3)	Inspire Super (3+9)	Pristine (7+11)	Captan (M) or Mancozeb (M)	Captan (M) or Mancozeb (M)				
							Critical Period								

2. STRATEGIC TIMING OF FUNGICIDES

- Apply fungicides to prevent inoculum buildup and protect the foliage and clusters from initial (primary) infections

32

Tips for Strategic Timing of Fungicides-Early Season

- Use protectants during rapid growth early in the season
- Biocontrols are most effective when disease pressure is low

Spray No.	0	1	2	3	4	5
Growth Stage	Dormant	Bud Break	1 inch	3-5 inch	6-9 inch	10-12 inch
	Anthracnose		Phomopsis			
	Sulforix		Mancozeb (M)	Mancozeb (M)	Mancozeb (M)	Mancozeb (M)
				Powdery Mildew		
				Stylet Oil	Sulfur (M) or LifeGard	Sulfur (M) or LifeGard
				Downy Mildew		
				Mancozeb (M)	Mancozeb (M)	Mancozeb (M)
						Black Rot
						Mancozeb (M)

33

Tips for Strategic Timing of Fungicides-Critical Period

- Avoid using FRAC 11 fungicides during critical period if **QoI resistance is confirmed** in your vineyard
- Tank mix with a protectant if appropriate

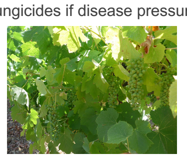
6	7	8	9	10
Pre-bloom to early bloom	Pre-bloom to early bloom	(1st post-bloom)	Pea-size (2nd post-bloom)	Pea-size (3rd post-bloom)
Revus Top (40+3)	Inspire Super (3+9)	Pristine (7+11) or Sulfur (M)	Quintec (13)	Torino (U6)
Revus Top (40+3)	Zampro (45+40)	Pristine (7+11)	Captan (M) or Mancozeb (M)	Captan (M) or Mancozeb (M)
Revus Top (40+3)	Inspire Super (3+9)	Pristine (7+11)	Captan (M) or Mancozeb (M)	Captan (M) or Mancozeb (M)
Critical Period				

34

Tips for Strategic Timing of Fungicides-Late Season

- Use best cultural practices and fungicides to keep inoculum levels low
- Use protectants and/or alternate with systemic fungicides if disease pressure is low
- Tank mix protectants with systemic fungicides if disease pressure is high

11	12	13	14
Berry Touch (4th post-bloom)	Berry Touch (5th post-bloom)	Veraison	Pre-harvest
Botrytis Bunch Rot			
Vangard (9)	Vangard (9)	Endura (7)	
Quintec (13) or LifeGard	Torino (U6)	Vivand (U8) or LifeGard	Potassium salts
Captan (M)	Captan (M)	Captan (M)	Potassium salts or Revus (40)



35

Table 2. Vivando® fungicide Crop-specific Requirements *(continued)*

Crop	Target Disease	Product Use Rate per Application (fl ozs/A)	Maximum Number of Applications per Year	Maximum Product Rate per Year (fl ozs/A)	Minimum Time from Application to Harvest (PHI) (days)
Grapes	Powdery mildew *Erisyphe* spp.	10.3 to 15.4 (0.2 to 0.3 lb ai)	3	46.2 (0.9 lb ai)	14

Application Directions. For control of powdery mildew, begin **Vivando** applications at bud break prior to onset of disease, using 10.3 to 15.4 fl ozs/A (0.2 to 0.3 lb ai) and continue on a 14 to 21 day interval.

Use the higher rate and the shorter interval when disease pressure is high.

Vivando must be applied before visual symptoms of powdery mildew appear. **Vivando** has no curative properties and will not control latent or established infections of powdery mildew. If powdery mildew infection is established, **Vivando** should be applied in a tank mix combination or following application of a curative fungicide.

DO NOT apply at rates higher than 15.4 fl ozs product (0.3 lb ai). **DO NOT** apply more than 46.2 fl ozs/A (0.9 lb ai) per year. The minimum interval between sprays is 14 days.

DO NOT mix **Vivando** with horticultural oils when making applications to grapes **after flowering begins**.

Resistance Management. To limit the potential for development of resistance, **DO NOT** make more than three (3) **Vivando** applications per year.

DO NOT make more than two (2) sequential **Vivando** applications before alternating to a labeled fungicide with a different mode of action.

3. OPTIMAL SPRAY INTERVALS

- The duration of the efficacy is influenced by the mobility, rate, mode of action and environmental conditions

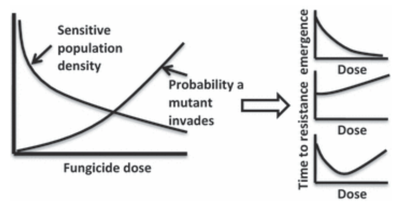
36

Tips for Selecting the Application Interval

Short Intervals (5-10 days)
- Protectants and some translaminar products
- Biocontrol products
- Rapid plant growth periods
- Environmental conditions that favour pathogen growth=high disease pressure

Long Intervals (>10 days)
- Translaminar and systemic products
- Periods of slow plant growth
- Low disease pressure environmental conditions

37



Plant Pathology, Volume: 60, Issue: 4, Pages: 597-606, First published: 06 March 2011, DOI: (10.1111/j.1365-3059.2011.02439.x)

4. USE THE CORRECT RATE (DOSE)

- The time until fungicide resistance emerges in the pathogen population is a combined effect of **dose on pathogen population density, mutation rate and the probability to invade**

38

Evolving to resistance may take many generations, therefore "much of the opportunity to slow evolution (resistance development) has already been lost if resistance management strategies are put in place in response to detection."

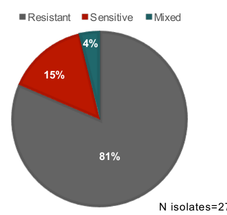
Hobbelen et al. 2014. PLOS One DOI: 10.1371/journal.pone.0091910 · Source: PubMed

39

QoI Resistance is in my Vineyard! What do I Do?

- Don't panic and ask for help!
- Plan a resistance management program
  - Reduce use of QoI fungicides (use early in the season but avoid critical period)
  - Mix protectants with QoI fungicides
  - Rotate FRAC groups (mode of action)
  - Avoid extending spray intervals

The presence of the resistance gene does NOT mean control failure is eminent.



N isolates=27
N farms=7

40

Control problems last year?	G143A Results	Time of Sampling	Interpretation
No	Sensitive		Can use FRAC 11 fungicides tank-mixed with fungicides of the other FRAC groups or multi-site fungicides.
No	Less than 50% of samples from a block are designated "Resistant" or "Mixed"	Up to the first 3 sprays of the season	Do not use FRAC 11 fungicides until after two multi-site fungicide applications have occurred.
		Bloom to pea-size berries	Do not use FRAC 11 fungicides for the rest of the season.
		Pea-size berries to harvest	Can use FRAC 11 fungicides tank mixed with a multi-site fungicide.
	More than 50% of samples from a block are designated "Resistant" or "Mixed"	Before pea-size berries	Do not use FRAC 11 fungicides for the rest of the season.
		Pea-size berries to harvest	Can use FRAC 11 fungicides tank-mixed with other fungicides.
Yes	Sensitive		Can use FRAC 11 fungicides tank-mixed with other fungicides. Check sprayer calibration and droplet size, application volume, and deposition. Consider shortening application interval and slowing tractor speed (adjust calibration accordingly).
	Any sample results from a block are designated "Resistant" or "Mixed"		Do not use FRAC 11 fungicides for the rest of the season. Check sprayer calibration and droplet size, application volume, and deposition. Consider shortening application interval and slowing tractor speed (adjust calibration accordingly).

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41

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FRAME networks

42