A3878

Fungicide resistance management in corn, soybean, and wheat in Wisconsin

Fungicides are important tools for managing plant diseases in corn, soybean, and wheat. Unlike insecticides and herbicides that are used to kill insects and weeds, fungicides act as a barrier to protect healthy plant tissues from infection by fungi. Due to the protective nature of fungicides, they should be applied in a spray volume that provides sufficient coverage of plant tissues. Fungicides are often reapplied to plants because they can be degraded by time and weathering, and are needed to protect new plant growth. Poor disease control can result from weathering, insufficient fungicide coverage, low application rates, poor efficacy of the selected fungicide on the pathogen of concern, and fungicide resistance (insensitivity to the fungicide). Fungicide resistance results from a complex interaction between fungicide mode of action, fungus biology, frequency of fungicide use, fungicide application, and cropping system.

Fungicide mobility

Understanding fungicide mobility can provide valuable information about fungicide selection and help you decide whether or not to use a fungicide. Fungicides are classified into two basic groups: contacts and penetrants. Regardless of mobility, fungicide efficacy will be limited when applied after symptom development and pathogen reproduction (spore production). Fungicides will not cure existing disease symptoms. However, timely application can result in slowing or eliminating symptom development and stop pathogen reproduction. Applying fungicides before a pathogen is well-established results in the best control.

Contact fungicides remain on the plant surface. They do not move on or into plant tissues and can be readily washed from the plant surface. Contact fungicides must be reapplied to protect new plant growth. Because of the limited mobility of contact fungicides and their protectant-only nature, these products should be used prior to fungal infection.

Penetrant fungicides are absorbed into plants after being applied to the surface. Because of the movement of the fungicide into the plant, these fungicides are generally considered systemic fungicides. This can be misleading since the degree of systemicity can vary among fungicides. Local penetrant fungicides only move a short distance, such as into the waxy plant cuticle, and remain in that location. Translaminar penetrants can move through the cuticle between cells toward the opposite side of the leaf. Acropetal penetrants are xylem- (water conducting elements of plants) mobile and move between cells along a water potential gradient. Acropetal penetrants only move upwards in plants. Systemic penetrants move through cells and follow sugar gradients in plants. Therefore, systemic penetrants can move upward and downward in plants. Very few fungicides are considered systemic penetrants. Regardless of the level of systemicity, penetrant fungicides have very limited curative ability. Penetrative fungicides will only stop or slow infections within the first 24–72 hours after infection. Therefore, best control of fungal infection with penetrant fungicides is achieved when these products are applied on a preventative schedule.

Fungicide resistance in fungi

Fungicide resistance is defined as a genetic adjustment of the fungus that leads to reduced sensitivity to a fungicide. Genetic mutations in fungi that result in fungicide resistance are thought to occur at low frequency and can be governed by a single gene or multiple genes. Mechanisms that lead to reduced sensitivity to a fungicide can vary, but include the alteration of the target site, reduced fungicide uptake, active export of the fungicide out of the fungal cell, and breakdown of the fungicide active ingredient. Fungicide resistance in fungi becomes a problem when the frequency of resistant strains in the population outnumbers the fungicide-sensitive individuals. This arises through repeated and exclusive use of at-risk fungicides. Selection pressure can

be high when repeated fungicide applications are used to control many foliar diseases. Risk of fungicide resistance development is low for seed treatments and soilborne pathogens, which require one or two applications per season for control.

Practices that result in fungicide resistance

Application of fungicide at the wrong time (e.g., after the fungus has begun reproduction) or with inadequate coverage can result in poor control of a disease and lead to reapplication; this results in many individuals being exposed to the fungicide. Using inadequate rates can also lead to poor control and the need to apply fungicides frequently and exposing many individuals to the fungicide. Excessive application of fungicide where a need is not justified can also lead to higher risk of fungicide resistance. Other practices that result in unnecessarily high populations of fungal individuals being exposed to excessive fungicide application include using susceptible hybrids/varieties, inadequate or excessive fertilization, excessive and/or frequent irrigation, continuous cropping, and poor sanitation.

FRAC and the FRAC code

The Fungicide Resistance Action Committee (FRAC) is an organization made up of representatives of the agrochemical industry. Their mission: "… is to provide fungicide resistance management guidelines to prolong the effectiveness of 'at risk' fungicides and to limit crop losses should resistance occur." FRAC developed a code, known as the FRAC Code, which can be used to classify fungicides into groups based on their mode of action. Fungicides currently registered in Wisconsin for use on corn, soybean, and wheat fall into six FRAC Codes: 1, 3, 4, 7, 11, and M.

FRAC Code 1: The methyl benzimidazole carbamate (MBC) fungicide group contains the benzimidazole and thiophanate fungicide families. These fungicides are effective against a broad range of fungi that cause leaf spots, root and crown rots, stem rots, and powdery mildews, but not rusts. MBC fungicides inhibit tubulin production, interfering with normal cell division in sensitive fungi. These fungicides have preventative and early-infection activity. While they have penetrant properties, they cannot move down in the plant, making canopy penetration and complete plant coverage essential for control.

The MBC fungicide risk of resistance is high. The modification of a single amino acid in a fungus can result in resistance. Resistance to these fungicides was first reported in 1970. Many important fungal plant pathogens have become resistant to these fungicides.

FRAC Code 3: The demethylation inhibitors (DMI) fungicide group contains the triazole fungicides. DMI fungicides are highly effective against powdery mildews, rusts, and many leaf spotting fungi. These fungicides work by inhibiting a specific enzyme that plays a role in sterol production in fungi. Sterols are necessary for the development of functional cell walls in fungi. Application of DMIs results in abnormal fungal growth and death. However, triazoles have no effect on spore germination because spores contain enough sterol for the formation of germ tubes. Thus, DMI fungicide must be applied preventively or at early infection to be effective. DMI fungicides are acropetal penetrant fungicides, meaning that they are taken up into the plant and can move short distances in the water-conducting elements (xylem) of plants. Generally, these fungicides have approximately 14 days of residual activity.

DMI fungicides have a very specific site of action, so risk of resistance development is a concern. Resistance management practices include avoiding repeated applications of DMI fungicides in the same season against high-risk pathogens such as powdery mildew.

FRAC Code 7: Carboxamide fungicides include boscalid, carboxin, and flutolanil. Boscalid is primarily a foliar fungicide used against the *Botrytis, Sclerotinia*, and *Alternaria* pathogens. They work by inhibiting the respiration of target fungi, specifically complex II fungal respiration. Carboxamide fungicides are acropetal penetrant fungicides, meaning that they are taken up into the plant and can move short distances in the water-conducting elements (xylem) of plants. Resistance has been documented for these fungicides.

FRAC Code 11: The Quinone outside inhibitors (QoI) fungicide group contains three fungicide families: strobilurins, imidazoles, and oxazoles. QoI fungicides are very effective against a broad spectrum of fungi. These fungicides work by inhibiting mitochondrial respiration, effectively stopping energy production of the fungus, and result in death. These fungicides are effective on spore germination and early growth. QoI fungicides vary on their mobility in plants. Some are local penetrants, while others are acropetal penetrants. Regardless of mobility in the plant, QoI fungicides are not effective against fungi that are growing inside the leaf tissue, so they must be applied preventively or at early infection to be effective. These fungicides have approximately 7–21 days of residual activity.

QoI fungicides have a very specific site of action, so the risk of resistance development is a high. Currently there are more than 20 plant pathogens with some level of resistance to QoI fungicides.

Guidelines for fungicide resistance management

- Plant disease-resistant hybrids/varieties whenever possible.
- Maintain proper soil fertility.
- Scout fields on a regular basis, noting incidence and severity of diseases. Use this information to develop a field history for future disease management decisions.
- Avoid sites with a history of high disease pressure.
- Utilize a crop rotation that fits your area and field history.
- Tank mix high-risk fungicides with fungicides that have different modes of action, are active against the targeted disease(s), and have similar lengths of residual activity.
- Do not use reduced rates of fungicides.
- Alternate or tank mix fungicides with different modes of action when multiple applications are required.
- Apply fungicides preventively or early in the disease cycle and when a disease threat is warranted.
- Avoid curative fungicide applications, especially with high-risk fungicides.

FRAC Code M: Multi-site activity fungicides include inorganic compounds (M1), dithiocarbamates (M3), and chloronitriles (M5). Multi-site activity fungicides have a broad spectrum of disease control activity. They are contact fungicides and should be used preventatively since they are applied to the leaf and stem surfaces prior to pathogen appearance. They do not affect fungi once they have infected the plant. Multi-site activity fungicides affect multiple biochemical sites in fungi, killing fungi by overwhelming them with toxins. These fungicides are sensitive to rainfall and sunlight since they are not absorbed into the plant, generally remaining active for 7–14 days.

Multi-site activity fungicides have a low risk of resistance development. Because of this, multi-site activity fungicides are an important part of fungicide resistance management. When multi-site fungicides are combined with either a code 3 or 11 fungicide (if allowed by the fungicide label), they may extend the number of years those higher risk fungicides can be used by reducing the number of applications of those high-risk fungicides.

Always read and follow the pesticide label:

- for maximum number of sprays per season.
- for recommended application rates.
- for application timing for both target disease and plant growth stage.

Text adapted from:

Damicone, John and Damon Smith. 2009. *EPP-7663 Fungicide Resistance Management*. Oklahoma State University Cooperative Extension Service Fact Sheet.

Mueller, Daren S. and Carl A. Bradley. 2008. *Field Crop Fungicides for the North Central United States*. Ames, IA and Urbana-Champaign, IL: Iowa State University and University of Illinois North Central Integrated Pest Management Center.

The Fungicide Resistance Action Committee provides a list of fungicides sorted by modes of action:

www.frac.info/frac/index.htm.

Table 1. Individual fungicides listed by FRAC code

FRAC CODE	GROUP NAME	CHEMICAL FAMILY	ACTIVE INGREDIENT	PATHOGEN RESISTANCE?	MANUFACTURER	PRODUCT EXAMPLE	CROP* REGISTERED FOR
No Code			*Coniothyrium minitans*	**No**	Prophtya	Contans WG	Soybean
1	MBCs	thiophanates	thiophanate-methyl	Yes	United Phosphorus	Topsin® M 4.5FL	Soybean
						Topsin® M 70WP	Soybean
						Topsin® M 70WDG	Soybean
						Topsin ® M WSB	Soybean
					Makhteshim-Agan	Incognito	Soybean
						Thiophanate Methyl 85 WDG	Soybean
					Nufarm Agricultural chemicals	Nufarm T-Methyl	Soybean
3	DMIs	triazole	cyproconazole	Yes	Syngenta	Alto 100SL	Soybean, Wheat
			flutriafol	Yes	Cheminova	Topguard	Corn, Soybean
			metconazole	Yes	BASF	Caramba™	Wheat
			myclobutanil	Yes	Dow AgroSciences	Laredo EC	Soybean
			tebuconozole	Yes	Bayer CropScience	Folicur®	Wheat
					Loveland Products	Monsoon	Corn, Soybean, Wheat
					SipCam Advan	Muscle	Soybean, Wheat
					Winfield Solutions	Onset	Corn, Soybean, Wheat
					Makhteshim-Agan	Orius	Corn, Soybean, Wheat
			tetraconazole	Yes	Valent	Domark® 230 ME	Corn, Soybean
			propiconazole	Yes	Syngenta	Tilt®	Corn, Soybean, Wheat
					Dow AgroSciences	PropiMax® EC	Soybean, Wheat
					Makhteshim Agan.	Bumper 41.8 EC	Corn, Soybean, Wheat
						Bumper ES	Corn, Soybean, Wheat
					Loveland Products	Fitness	Corn, Wheat
					Direct Ag Source	Propicure	Corn, Soybean, Wheat
					Winfield Solutions	Topaz	Corn, Soybean, Wheat
					Amtide	Amtide Propiconazole	Corn, Soybean, Wheat
			prothioconazole	Yes	Bayer CropScience	Proline® 480SC	Corn, Soybean, Wheat
7	SDHI	pyridine-carboximide	boscalid	Yes	BASF	Endura®	Soybean
		pyrazole-carboximide	penthiopyrad	Yes	DuPont	Vertisan	Corn, Soybean, Wheat

11	QoIs	methoxycarbamate	pyraclostrobin	Yes	BASF	Headline®	Corn, Soybean, Wheat
		methoxyacrylate	azoxystrobin	Yes	Syngenta	Quadris®	Corn, Soybean, Wheat
			picoxystrobin	Yes	DuPont	Aproach	Corn, Soybean, Wheat
		dihydro-dioxazine	fluoxastrobin	Yes	Arysta LifeSciences	Evito	Soybean, Corn, Wheat
					Loveland Products	Aftershock	Soybean, Corn, Wheat
M	M1	inorganic	copper hydroxide	**No**	DuPont	Kocide® 3000	Corn, Soybean, Wheat
						Kocide ® 2000	Corn, Soybean, Wheat
					Albaugh Inc./Agri Star	Nu-Cop 3 L	Wheat
						Nu-Cop HB	Wheat
			copper octanoate	**No**	Certis	Cueva	Corn
			copper sulfate	**No**	United Phosphorus	Cuprofix® Ultra 40 Disperss	Soybean, Wheat
	M3	dithiocarbamate	mancozeb	**No**	Dow AgroSciences	Dithane® DF Rainshield™	Corn, Wheat
						Dithane® F-45 Rainshield™	Corn, Wheat
						Dithane® M45	Corn, Wheat
					Cheminova	Koverall	Corn, Wheat
					United Phosphorus	Manzate® ProStick™	Corn, Wheat
						Manzate® Flowable™	Corn, Wheat
						Penncozeb™ 75DF	Corn, Wheat
						Penncozeb™80WP	Corn, Wheat
						Penncozeb™ 4FL	Corn, Wheat
	M5	chloronitriles	chlorothalonil	**No**	Syngenta	Bravo WeatherStik®	Soybean
						Bravo® Ultrex	Soybean
						Chloronil 720	Corn, Soybean
					Sipcam Agro USA	Echo® 720	Corn, Soybean
						Echo® 90DF	Corn, Soybean
						Echo® Zn	Corn, Soybean
					Arysta LifeSciences	Chlorothalonil 720 SC	Soybean, Corn
					Makhteshim-Agan	Equus 500 ZN	Soybean, Corn
						Equus 720 SST	Soybean, Corn
						Equus DF	Soybean, Corn
					Loveland Products	Initiate	Soybean, Corn
						Initiate ZN	Soybean, Corn

* MAY BE REGISTERED ON CROPS OTHER THAN CORN, SOYBEAN, OR WHEAT. SEE LABEL FOR INFORMATION.

Table 2. Premix fungicides listed by FRAC code

FRAC CODE	GROUP NAME	CHEMICAL FAMILY	ACTIVE INGREDIENT	PATHOGEN RESISTANCE?	MANUFACTURER	PRODUCT EXAMPLE	CROP* REGISTERED FOR
M1	M1	inorganic	copper hydroxide	**No**	Isagro	Badge X2	Corn
M1			copper oxychloride	**No**			
3	DMI	triazole	propiconazole	Yes	United Phosphorus	Topsin Xtra	Soybean
1	MBCs	thiophanate	thiophanate-methyl	Yes			
3	DMI	triazole	prothioconazole	Yes	Bayer	Prosaro™ 421 SC	Wheat
3	DMI	triazole	tebuconazole	Yes			
3	DMI	triazole	propiconazole	Yes	Syngenta	Quilt®	Corn, Soybean, Wheat
11	QoI	methoxyacrylate	azoxystrobin	Yes			
3	DMI	triazole	propiconazole	Yes	Syngenta	Quilt® Xcel	Corn, Soybean, Wheat
11	QoI	methoxyacrylate	azoxystrobin	Yes			
3	DMI	triazole	propiconazole	Yes	Helena Chemical	Avaris™	Corn, Soybean, Wheat
11	QoI	methoxyacrylate	azoxystrobin	Yes			
3	DMI	triazole	propiconazole	Yes	Helena Chemical	HM-0812®	Corn, Soybean
11	QoI	methoxyacrylate	azoxystrobin	Yes			
3	DMI	triazole	cyproconazole	Yes	Syngenta	Quadris Xtra™	Soybean
11	QoI	methoxyacrylate	azoxystrobin	Yes			
3	DMI	triazole	difenoconazole	Yes	Syngenta	Quadris Top™	Soybean
11	QoI	methoxyacrylate	azoxystrobin	Yes			
3	DMI	triazole	metconazole	Yes	BASF	Headline AMP™	Corn
11	QoI	methoxycarbamate	pyraclostrobin	Yes			

3	DMI	triazole	metconazole	Yes	BASF	Twinline™	Wheat
11	QoI	methoxycarbamate	pyraclostrobin	Yes			
3	DMI	triazole	tebuconazole	Yes	Bayer CropScience	Absolute 500 SC	Wheat
11	QoI	oximinoacetate	trifloxystrobin	Yes			
3	DMI	triazole	prothioconazole	Yes	Bayer CropScience	Stratego® YLD	Corn, Soybean, Wheat
11	QoI	oximinoacetate	trifloxystrobin	Yes			
3	DMI	triazole	propiconazole	Yes	Bayer CropScience	Stratego®	Corn, Soybean, Wheat
11	QoI	oximinoacetate	trifloxystrobin	Yes			
7	SDHI	pyrazole-carboxamide	fluxapyroxad	Yes	BASF	Priaxor	Corn, Soybean, Wheat
11	QoI	methoxycarbamate	pyraclostrobin	Yes			

* MAY BE REGISTERED ON CROPS OTHER THAN CORN, SOYBEAN, OR WHEAT. SEE LABEL FOR INFORMATION.

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