Editors' Note: This is the fourth in a seven-part series on research being performed at North Carolina State University in Raleigh, N.C.

Facing the Downy Mildew Dilemma

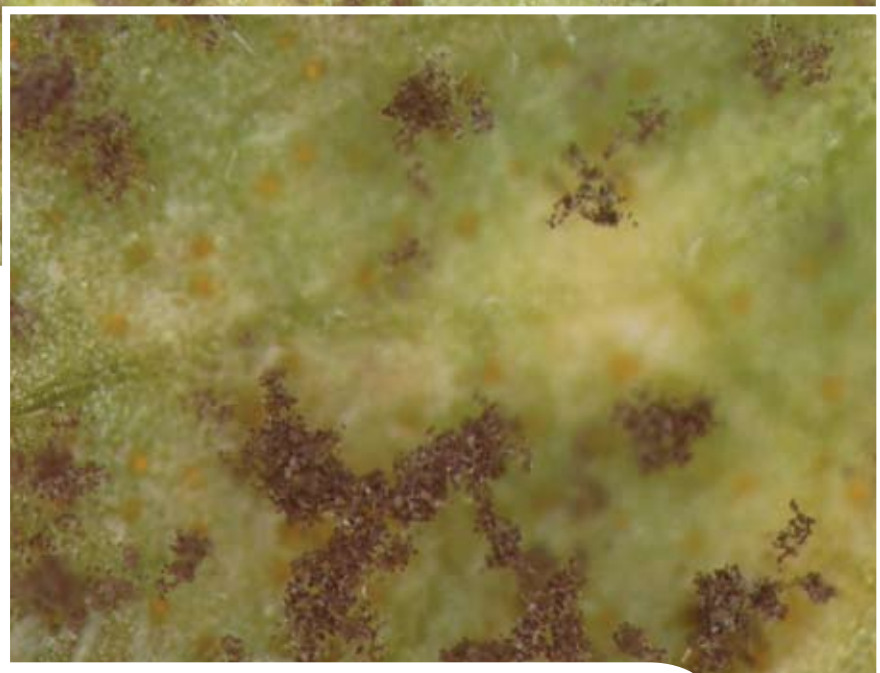
> While little is known about these plant pathogens, the little you do know will help your control strategies.

By Kelly Ivors

Worried about downy mildew this spring? There's nothing wrong with that — you should be. We know relatively little about these kinds of plant pathogens; and what you don't know can hurt you!

The downy mildews are recognized as some of the most destructive yet mysterious plant pathogens in commercial agriculture, reflected by their highly specialized association with host plants, their specialized spore structures for wind dispersal and long-range transport, and their high "evolutionary potential" for mutation and genetic variation.

At current, there are more than 17 distinct genera of downy mildew organisms recognized, with the genera Peronospora, Plasmopara, Bremia and Pseudoperonospora most commonly known. The range in host plants that get



Figures 1 and 2: *Detection of downy mildew is typically based on foliar symptoms and the presence of spore clusters on the underside of infected leaves.*

Figure 3: *During prolonged cool and humid conditions, highly specialized structures called sporangiophores emerge through stomata of infected plant foliage and produce new sporangia on their tips.*

mildew increases every year and encompasses hundreds of different plant species; some of the ornamental plants more commonly identified with downy mildew diseases in the southeastern United States would include: basil, buddleia, coleus, lamium, redbud, rose, rosemary, salvia, snapdragon and sunflower.

In recent years, several new, previously undescribed downy mildew species and strains have appeared in various U.S. ornamental and vegetable crops (such as coleus, basil and cucurbits), raising concern about our ability to effectively manage these diseases. New strains of previously known downy mildew species have also appeared that are insensitive to commonly used fungicides. The rapid evolution of these downy mildew pathogens has played a significant role in the ineffectiveness

of durable host plant resistance and the development of fungicide insensitivity.

What We Do Know About Downy Mildew

Symptom expression of downy mildew often depends on the greenhouse environment and the particular host plant infected. Detection of downy mildew is typically based on foliar symptoms and the presence of spore clusters on the underside of infected leaves (Figures 1 and 2). These spores, known as sporangia, may be few in number and very difficult to see without a hand lens or microscope. It's possible for the pathogen to remain dormant until environmental conditions become favorable. In general, optimal conditions for infection and sporulation are high relative humidity and temperatures ranging from 50 to 70° F. Downy mildew spores then germinate and infect through the cuticle or stomates of the host plant. Usually it can take anywhere from six to 12 days for the plant to show foliar symptoms after initial infection.

During prolonged cool and humid conditions, highly specialized structures called sporangiophores emerge through stomata (Figure 3) of infected plant foliage and produce new sporangia on their tips; these spores get dislodged (Figure 4) during rain and wind events, which then travel short and/or long distances to infect new plants.

Fungicides have been used to control downy mildew diseases for many years. Metalaxyl (and now the related isomer mefenoxam), a systemic fungicide, was the primary chemical used for the control of downy mildew pathogens but resistance to this chemistry in populations of some downy mildews was first reported in the 1980s in Mexico and later in the United States. Since this time, many trials have been conducted to identify alternative, effective fungicides for controlling downy mildew. The development of insensitivity to mefenoxam in many downy mildew pathosystems is why growers observe variable responses in disease control after applying this chemistry; sometimes it works, and sometimes it has no effect. Table 1 provides a summary of results combined from over 25 different F&N and PDMR reports published throughout the years involving downy mildew fungicide trials from numerous specialists. In the past decade, many new chemistries that are very effective at controlling the downy mildews have been developed and include: fluopicolide, cyazofamid, mandipropamid (no ornamental label yet for mandipropamid) and the phosphonates.

Table 1. Relative effectiveness of various chemicals for downy mildew control in ornamentals — Compiled by Kelly Ivors

Relative control rating: E= excellent control (100-85%); G= good control (84-70%); F= fair control (69-50%); P= poor control (49-0%).

Trade name	Active ingredient(s)	FRAC[1]	Sites[2]	Efficacy rating	Notes
Subdue Maxx	Mefenoxam	4	G, N, L	E to P [Dr, R]	A granular formulation of Subdue can also be mixed into the substrate.
Compass O	Trifloxystrobin	11	G, N, L	G [S]	Do not mix with organosilicone adjuvants.
Disarm	Fluoxastrobin	11	G, N, L	E [S]	
FenStop	Fenamidone	11	G	E [S]	
Heritage	Azoxystrobin	11	G, N, L	G [S]	Do not mix with organosilicone adjuvants.
Terrazole / Truban	Etridiazole	14	G, N, La	G [Dr]	
Stature	Dimethomorph	15	G, N	G [S, Dr]	Active ingredient may settle out of solution; requires agitation if left to sit.
Segway	Cyazofamid	21	G, N, L	G [S, Dr]	
Aliette	Fosetyl AL	33	G, N, L	E [S]	Aliette is not compatible with flowable formulations of Daconil, Fore or copper fungicides as tank mixtures.
Alude / Fosphite / K-Phite / Magellan	Mono- and di-potassium salts of phosphorous acid	33	G, N, L	G to F [S]	Do not apply to plants under severe water stress or during very HIGH or very LOW temperatures.
Vital	Potassium phosphite	33	G, N, L	G to F [S]	
Adorn	Fluopicolide	43	G, N, L	E to G [S, Dr]	Adorn MUST be tank mixed for resistance management with another product that is registered for use against the target disease.
Protect / Fore	Mancozeb	M3	G, N, L	G [S]	
Regalia	Extract of Giant Knotweed (Reynoutria sachalinensis)	NA	G, N, L	F to P [S]	Concentrations at 1% or higher applied on young tissue may cause phytotoxicity.

[1] Key to Fungicide Groups: 4: phenylamides; 11: quinone outside inhibitors; 14: aromatic hydrocarbons and heteroaromatics; 15: cinnamic acids; 21: quinone inside inhibitors; 33: phosphonates; 43: acylpicolides; M: multi-site activity; NA: not applicable.

[2] Product labeled for use in G = greenhouse; N = nursery; L = landscape.

[Dr] = Product should be applied as a drench.

[S] = Product should be applied as a foliar spray.

[R] = Resistance to this pesticide has been detected in the pathogen population.

[a] = Terrazole is for commercial use ONLY; label restricts the use of Terrazole in residential greenhouses or indoor plant sites.

Note: Recommendations for the use of agricultural chemicals are included here as a convenience to the reader. The use of brand names and mention or listing of commercial products does not imply endorsement nor discrimination against similar products or services not mentioned. Individuals who use agricultural chemicals are responsible for ensuring that the intended use complies with current STATE regulations and conforms to the product label. Examine a current product label before applying any chemical. For assistance, contact your county Cooperative Extension agent.

What We Don't Know About Downy Mildew

Little is known about the basic biology, specific host plant range, and genetic variability of most downy mildew species, mainly due to their "obligate" nature and difficulty in working with them. Obligate plant pathogens require a living host plant to reproduce and grow; they can not be cultured in the laboratory. The technical challenge of being unable to manipulate them in the laboratory is an inherent limitation to the development of better detection techniques and for the evaluation of host plant resistance and effective fungicides. Much of what we know has been derived from decades of studies involving the tobacco downy mildew pathogen, Peronospora tabacina.

Do basil and coleus get the same downy mildew? The host range of each different downy mildew species can be simple and involve a single plant species, or it can be complicated and involve many different host plants. For example, *Plasmopara halstedii* attacks more than 100 different plant species in the sunflower family Asteraceae, while *Peronospora antirrhini* only attacks snapdragons. A recent debate has been ongoing for several years regarding the host specificity of the new downy mildew that attacks coleus and whether or not it is the same new downy mildew species that also attacks basil. Early evidence from one European research group indicated that they were the

Figure 4 (top): *New sporangia produced on infected plant foliage gets dislodged during rain and wind, which then travel short and/or long distances to infect new plants.* ***Figure 5 (bottom):*** *Downy mildew sporulation occurring on the roots of a rose sample.*

same, but other DNA-based evidence from the United States indicates they are indeed different downy mildew species. In addition, numerous labs, including mine at North Carolina State University, have conducted inoculation studies and have not been successful at cross-infecting these strains on opposite hosts. I personally believe the coleus and basil downy mildews are distinct and not the same species. The inability to grow the downy mildews in the laboratory has impeded our progress on conducting similar trials on other economically important downy mildews.

I know I have downy mildew, but why can't I see it? A few studies have been carried out with respect to root transmission in non-ornamental downy mildew systems, and highlight the possibility that roots may provide an environment for prolonged propagation of the pathogen and could be an effective overwintering source. In addition, some downy mildews have the ability to cause systemic infections in their respective host plants, and survive internally within the plant's vascular system. Recently, the Plant Disease and Insect Clinic (PDIC) at North Carolina State University noticed downy mildew sporulation (*Peronospora sparsa*) occurring on the roots of a submitted rose sample (Figure 5). We need to start thinking more objectively about these pathogens and make better, strategic efforts to figure out where these pathogens survive and reproduce. Attempts to identify effective fungicides or genetic resistance in plants have typically focused on foliar protection and the ability to prevent spore germination, infection and growth on host leaves. Systemic and root infections are not typically addressed in current downy mildew disease management recommendations.

What We Need To Know About Downy Mildew

Downy mildews in general are considered high evolutionary risk plant pathogens due to their large effective population size (rampant spore production) and broad scale, intercontinental ability to spread. A thorough understanding of the genetics of these pathogens and mechanisms for their rapid development of new races would better enable breeders to develop longer-lasting durable resistance in host cultivars and lessen grower dependence on fungicides. Much work is also needed to address the biological and ecological complexities of important downy mildew pathogens in the field and greenhouse. Such basic information will no doubt have a significant impact on the advancement of science-based control strategies.

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