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POWDERY AND DOWNY MILDEWS ON GREENHOUSE CROPS

Although powdery mildew has a long history in greenhouse production, downy mildew has recently been the focus of attention and concern. Both diseases can contribute to significant economic losses in many greenhouse floricultural (e.g., snapdragons, poinsettias, violas, African daisy, and zinnias) and vegetable (e.g., basil, tomatoes, and cucumbers) crops. Although the two diseases share the name "mildew," they are very different. Powdery mildew infections reduce crop aesthetics and value but usually do not result in plant death. In contrast, downy mildew infections often result in plant death as well as the loss of aesthetics. An understanding of the differences between these diseases is important for recognition and successful management.

POWDERY MILDEW

SYMPTOMS:

Powdery mildews are easily recognized by the white, powdery growth of the fungus on infected portions of the plant host. The powdery appearance results from the threadlike strands (hyphae) of the fungus that grow superficially over the plant surface and produce chains of spores (conidia). Colonies vary in appearance from fluffy and white to sparse and gray. Powdery mildew fungi usually attack young developing shoots, foliage, stems, and flowers but can also colonize mature tissues. Symptoms often first appear on the upper surface of leaves but can also develop on the lower surfaces. All aboveground parts of plants can be infected. Early symptoms are variable and can be subtle, appearing as irregular chlorotic or purple areas or as necrotic lesions. These symptoms are followed by the typical white, powdery appearance (Figures 1, 2, 3, and 4).

Figure 1. Powdery mildew on torenia.

Atypical symptoms include corky, scab-like lesions, witches'-brooms, twisting and distortion of newly emerging shoots,

premature leaf coloration and drop, slowed or stunted growth, and leaf rolling. In rare, but extreme situations, heavy infections cause plant death.

Figure 2. Powdery mildew on gerbera daisy.

Figure 3. Powdery mildew on verbena.

Although diagnosis of powdery mildew is not difficult, symptoms often escape early detection. When plants are not periodically monitored, symptoms that develop on lower or middle leaves aren't discovered until they are sporulating. This explains reports of sudden "explosions" of disease when the percentage of infected leaves increases from 10% to 70% in one week.

CAUSAL ORGANISMS AND DISEASE DEVELOPMENT:

Although powdery mildews have been recognized for years, many questions about their biology remain unanswered. Although the symptoms of powdery mildew diseases might be similar, the fungi responsible for them are more diverse and complex than previous thought. Powdery mildews have recently been reorganized into five tribes. This resulted in creating new genera and eliminating or merging others. The powdery mildew genera of primary importance to greenhouse production are *Podosphaera, Erysiphe, Leveillula, Golovinomyces,* and *Oidium.*

Powdery mildew fungi are obligate pathogens that require living hosts in order to complete their life cycles—therefore, they readily infect healthy, vigorous plants. Some powdery mildew fungi are host specific while others are generalists with many hosts. For example, *Sphaerotheca pannosa* var. *rosae* (syn. *Podosphaera pannosa)* is host specific and only infects rose. In contrast, *Erysiphe cichoracearum* var. *cichoracearum* (syn. *Golovinomyces cichoracearum*) can infect many hosts within several families including Cucurbitaceae, Asteraceae, Verbenaceae, and Malvaceae. Therefore, knowing the identity of a powdery mildew is helpful to determine the potential for spread to other crops in a greenhouse.

Powdery mildew fungi have relatively simple life cycles on most ornamentals. Spores (conidia) are produced singly or in chains on stalks (conidiophores) (Figure 5). Conidia are "powdery" and are readily disseminated by air currents in the greenhouse. After conidia land on plant surfaces, they germinate, penetrate the tissues, and send food-absorbing projections (haustoria) into the epidermal cells.

Threadlike strands of the fungus (hyphae) then grow over the surface of the infected plant part and eventually produce more conidiophores and conidia. The time between when conidia land to when new conidia are produced can be as short as 72 hrs but is more commonly 5-7 days. Powdery mildew conidia are unique since unlike most fungal spores, they do not require free moisture on plant surfaces in order to infect.

Figure 4. Powdery mildew colonies on cucumber transplant.

Figure 5. Chains of powdery mildew conidia growing the surface of a cucumber leaf.

In greenhouses, powdery mildews usually survive between crops as hyphae or fungal strands in living crop plants or in weedy hosts. Under certain circumstances, some powdery mildew fungi produce small, black, pepper-like resting structures called chasmothecia (formerly cleistothecia) (Figure 6). These structures allow the fungus to survive in the absence of a suitable host. However, the role of these resistant structures is probably insignificant in greenhouse situations since continuous cropping usually provides a constant source of living hosts.

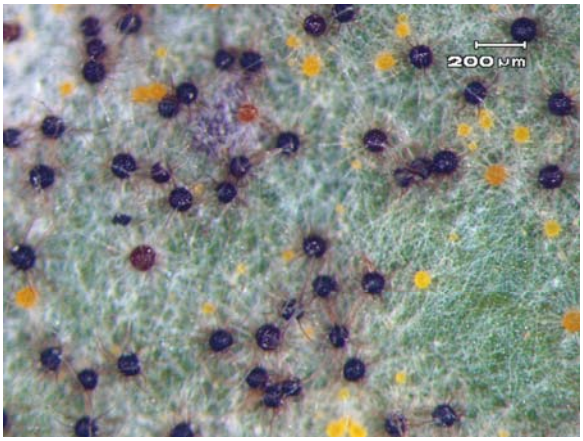

Figure 6. Powdery mildew chasmothecia formed on leaf surface. Chasmothecia are in different stages of maturity (yellow= immature; dark brown= mature)

Development of powdery mildew in the greenhouse is influenced by many environmental factors, including temperature, relative humidity (RH), light level, and air circulation. Unfortunately, greenhouses usually provide optimum levels for all of these conditions. Optimum conditions include moderate temperatures (68-86° F), high humidities (>95% RH), and low light intensities or shade. However, these requirements vary with the specific powdery mildew fungus. There is an inverse relationship between temperature and RH that influences production and

spread of powdery mildew conidia. As temperatures fall at night, RH increases. High RH stimulates conidia to germinate and encourages the production of chains of conidia. In the morning after sunrise, temperatures warm and RH levels fall. These conditions help to dry the chains of conidia prior to dissemination. Since conidia are the primary means for new infections in the greenhouse, air movement and circulation in the house are very important for initiating new infections and spreading disease. The dry, "powdery" conidia are easily dislodged and disseminated by air movement from opening and closing doors and grower activities.

DOWNY MILDEW

SYMPTOMS:

Downy mildews have become increasingly problematic in the horticultural industry and are currently causing serious losses in many floricultural crops. Key factors contributing to the extent of these losses are delayed recognition and misidentification. Symptoms first appear as subtle pale-yellow or light green areas on upper leaf surfaces. Infected leaves can also curl downward (Figure 7). On some hosts, downy mildew can result in irregular, angular lesions that can easily be confused with damage from foliar nematodes. In other cases, flower buds fail to form. Systemic symptoms can include stunting, leaf distortion and epinasty, shortened internodes, and decreases in the quantity and quality of flowers that are produced. Diagnostic symptoms gradually develop on the undersurface of the leaf as the pathogen grows out of the infected leaf. This growth appears as a fuzzy, tan-gray-purple-brown mass (Figure 8). Symptoms often go unnoticed until leaves brown, shrivel, and drop.

Figure 7. Impatiens with downy mildew. Note stunted plants and leaves that curl downwards.

Figure 8. Undersurface of impatiens leaf with abundant downy mildew sporulation (arrow).

CAUSAL ORGANISMS AND DISEASE DEVELOPMENT:

Downy mildews are fungus-like organisms or "water molds" that are more closely related to *Phytophthora* and *Pythium* than to the powdery mildews. The downy mildew genera of primary importance to greenhouse

crops are *Plasmopara* and *Peronospora*. The host ranges of downy mildew pathogens vary with species. However, the taxonomy and host specificity of these mildews is under revision as new information is acquired from molecular studies.

Downy mildews, like powdery mildews, are obligate pathogens that obtain nutrients from plant hosts. Downy mildews grow locally and systemically in plants and can escape detection until conditions are right for sporulation. They reproduce by forming sporangiophores and sporangia (sometimes called conidiophores and conidia) that develop and grow out of the undersurfaces of infected leaves. These can resemble bunches of grapes emerging from stomates (Figure 9). Each "grape" is a sporangium that, depending on species and other factors, germinates directly to form a germ tube or forms many zoospores. In either case, free water on the plant surface is essential for infection. This is a key difference in the environmental requirements that distinguish powdery from downy mildew. If zoospores are formed, they "swim" in the water, locate a host, and infect. As little as 6 hours of leaf wetness is necessary for infection. Both sporangia and zoospores can be spread by overhead irrigation or handling and by fans and air circulation.

In greenhouses, downy mildews can survive the "off-season" as mycelium in "over-seasoning" weeds and host plants. They can also form thick-walled oospores, which are resting (survival) structures embedded in dead leaves and other host tissues. The role of these resistant structures is probably insignificant in greenhouse situations since continuous cropping usually provides a constant source of living hosts. For some types of downy mildew (e.g., downy mildew of cucurbits, blue mold of tobacco), infections are established by sporangia that are carried by moist air currents that blow north from southern regions during the growing season. Other downy mildews can be seed-borne.

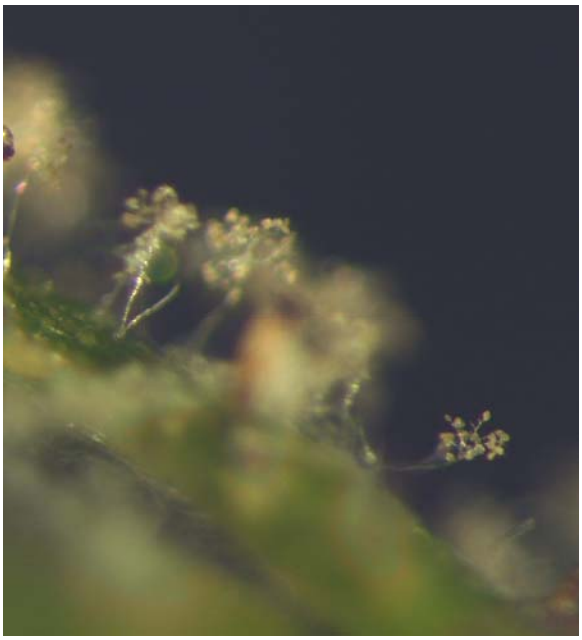

Figure 9. Downy mildew sporangia on sporangiophores emerging from the undersurface of a leaf.

Development of downy mildew in the greenhouse is influenced by many environmental factors including temperature, RH, light level, and air circulation. Optimal temperatures range from 45-70 °F, but these can vary with species. Humidity levels of 85% or higher are needed for sporulation and disease development. For many downy mildew species, sporangia are produced in the evening and released into the air the next morning. Sporangia are spread within the greenhouse via moist air currents, contaminated tools, equipment, fingers, and clothing. Sporangia are short-lived and become less infective under greenhouse conditions of high temperature and low humidity. They are also killed by intense sunlight. The infection to sporulation cycle

can be as short as four days, but is usually longer, around 7-10 days.

STRATEGIES FOR DISEASE MANAGEMENT:

An integrated approach is necessary to effectively manage powdery and downy mildews in the greenhouse.

1. Culture -

- Maintain adequate plant spacing to reduce RH levels in the plant canopy. This also helps to obtain good coverage when fungicides are used.
- Vent and heat to maintain RH levels below ~ 93%.
- Follow a sound cultural program to avoid stress (e.g., monitor nutrient levels, pH, and temperature). "Hungry" plants have been found to be more susceptible to downy mildew.
- Water management is essential for managing downy mildews. It is especially important to eliminate conditions that favor leaf wetness early in the day, since this condition is critical to downy mildew development. This can be accomplished by changing watering practices to reduce the amount of leaf moisture early in the day (i.e., change from overhead irrigation to spaghetti tubes, soaker hoses, or flood floors).

2. Sanitation-

- Carefully examine and inspect new cuttings, seedlings, and plugs upon arrival. Never accept or use diseased plant material.
- Quarantine new plant material, if possible. Try to segregate all new plant shipments from existing plants for the first several weeks.
- All diseased tissues should be removed as soon as they are detected and immediately placed in a plastic bag to avoid carrying infected material through the house.
- All production areas should be thoroughly cleaned and plant debris removed between crops and production cycles.
- Control weeds in and around the greenhouse since they can serve as reservoirs hosts of downy and powdery mildews.

3. Scout-

- Scout for disease on a regular schedule to identify outbreaks before they become widespread.
- With powdery mildew, this typically involves examining one out of 30 plants each week. It is helpful to concentrate on the middle and lower leaves since infections often start in these leaves. Once disease is detected, examine one out of 10 plants every week. Continue with this schedule until plants are free of disease for at least three weeks. Thereafter, resume weekly scouting of one plant out of 30.
- With downy mildew, scout at least once a week, preferably every 2-3 days. Look for symptoms on upper surfaces of leaves and turn leaves over to check for sporulation. Pay special attention to plants prone to downy mildew (e.g., impatiens, basil, coleus).

3. Resistance-

- Genetic resistance is very effective for managing powdery and downy mildew but it is unfortunately of limited availability for most floricultural crops. For example, in the "Fairway" series of coleus, 'Fairway Mosaic,' 'Fairway Red Velvet,' and 'Fairway Salmon Rose' have greater resistance to downy mildew than 'Fairway Ruby;' in the 'Festival' series of gerbera daisy, 'Festival Semi Double Orange' is more resistant to

4. Biological-

- These products need to be applied as protectants in order to be effective.

Powdery Mildew:

- *Bacillus subtilis* (Cease, Rhapsody, Serenade)
- *Trichoderma harzianum* Rifai strain KRL-AG2 (PlantShield)

Downy Mildew:

- *Bacillus subtilis* (Cease, Rhapsody, Serenade)
- *Trichoderma harzianum* Rifai strain KRL-AG2 (PlantShield).

5. Chemical-

- Several factors need to be considered when selecting fungicides for managing powdery and downy mildews. Among these are fungicide classes (MOA--FRAC Code) for resistance management, REI, environmental parameters (e.g., T, RH), compatibility, residue, and stage of the crop production cycle. In some cases, control is targeted at eradication of existing infections and protection of healthy tissues. Once disease is detected, the first sprays should be aimed at eradication. These are usually followed by sprays for protection. The efficacy of specific compounds can vary significantly with the pathogen and host. Attention to spray delivery and coverage is also very important.
- Since pesticide registrations vary with state, check with the appropriate agency and consult the label before applying any pesticide.

Fungicides for Powdery Mildew:

Systemics:

- Strobilurins [QoI] (Compass O, Cygnus, Insignia, Heritage)
- DMIs (Terraguard, Eagle, Hoist, Strike)
- Thiophanates (Cleary's 3336, OHP 6672)
- Carbamate and Strobilurin (Pageant)

Contacts (*Biorationals):

- Bicarbonates (Milstop, Kaligreen) *
- Coppers (Camelot, Kocide, Phyton 27)
- Hydrogen dioxide (ZeroTol, Oxidate)
- Sulfur (Microthiol Disperss)
- Oils: Horticultural & Neem (Ultra-Fine Oil, Triact) *
- Soaps (Insecticide Soap) *

Fungicides for Downy Mildew:

Systemics:

- Cinnamic Acid Amides (Stature DM)
- Phenylamide (Subdue Maxx)
- Phosphonates (Aliette, Alude, Vital)
- Strobilurins [QoI] (Compass O, Heritage, Cygnus, Fenstop, and Insignia)
- Carboxide and strobilurin (Pageant)

Contacts:

- Mancozeb (Protect, Dithane)
- Coppers (Kocide, Camelot, Phyton 27)

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