Powdery Mildew in Western Washington Commercial Grape Production: Biology and Disease Management

WASHINGTON STATE UNIVERSITY EXTENSION • EM059E

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Key Information

- The grapevine powdery mildew fungus prefers mild temperatures with high humidity. Only the very early stages of development require free water.
- High temperatures (>95°F) and low temperatures (<50°F) can debilitate or kill the fungus.
- Fruit are susceptible to infection from prebloom up to three weeks post fruit-set (Eichorn-Lorenz [EL] Stages 15-31; BBCH Stages 55-75).
- The pathogen *Erysiphe necator* can quickly develop resistance to fungicides, so proper selection of materials, rates, and use patterns is critical in preventing control failures due to resistance development. Proper selection is also important in preserving fungicide chemistries. Cultural practices that reduce disease pressure mitigate the potential for resistance development.

Figure 1. Severe powdery mildew infection on clusters can cause fruit cracking and arrested development (no sugar accumulation). Infections of this visible nature generally are not noticeable until just before véraison, even though infections likely occurred around bloom. Photo courtesy of Gary Grove.

Introduction

There are few plant diseases that have the same combination of international distribution and importance as grapevine powdery mildew (PM), which is present almost anywhere that susceptible grape varieties are grown. This disease, caused by the fungus *Erysiphe necator,* is believed to have originated in northeast North America, where the native grapevine species demonstrates a significant level of tolerance or resistance to this pathogen. However, the European wine grape species, *Vitis vinifera*, which did not evolve with this pathogen, is susceptible and severe symptoms can occur on fruit, foliage, and shoots of the plant when spread of the pathogen is extensive (Figures 1-3). Severe cluster infections render the fruit unusable, and even modest infections can predispose fruit to secondary invasion by spoilage microorganisms and Botrytis bunch rot (BBR). Foliar infections can significantly reduce the photosynthetic capacity of the plant and, in severe cases, cause premature defoliation. Heavy, early-season infections can predispose buds and canes to winter injury by compromising tissue integrity.

Figure 2. In severe cases, or shaded canopies, powdery mildew colonies can be found on the upper and lower leaf surfaces. On leaves exposed to the sun, colonies are likely to be found on the lower leaf surface only. Photo courtesy of Michelle Moyer.

Biology and Disease Development

It is important to understand the powdery mildew pathogen and its disease epidemiology in order to develop effective control strategies. There are features

Figure 3. Shoots infected by powdery mildew exhibit classic, grey web-like scarring (top left). From fall periderm formation (top right) until spring (bottom left), these infections are noticeable as brown to red web-like discolorations on the cane. Photo courtesy of Michelle Moyer.

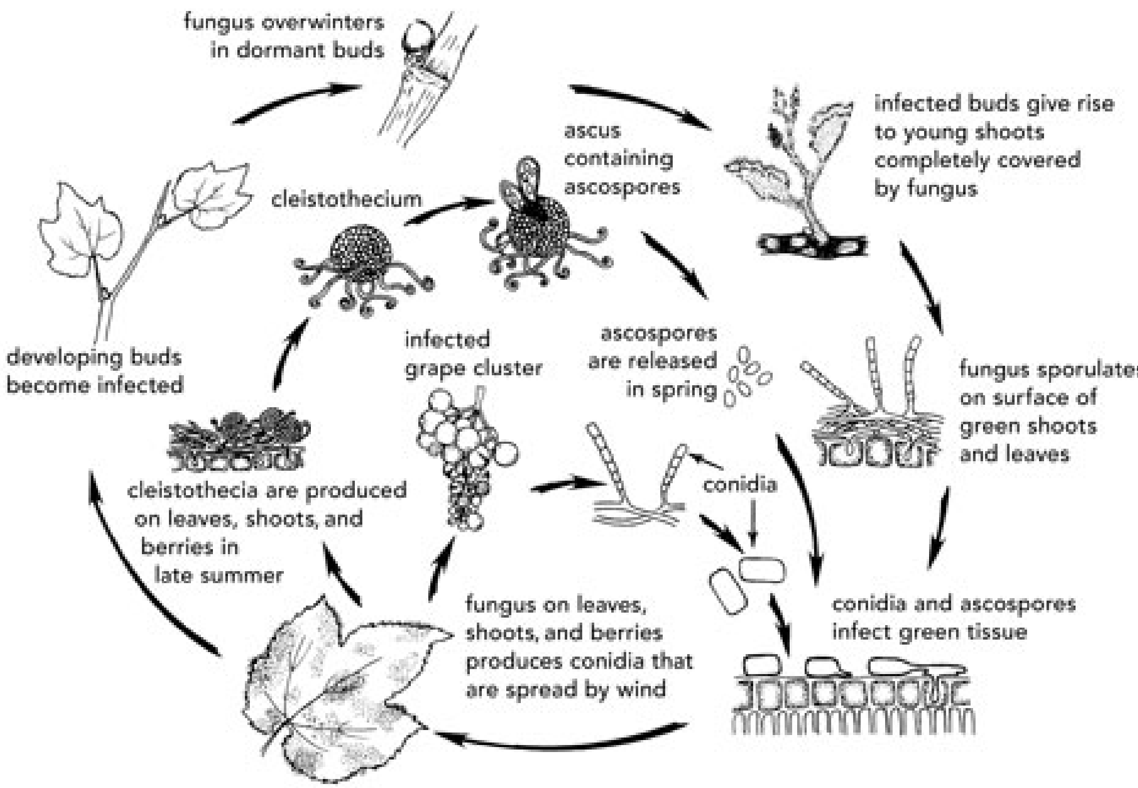

Figure 4. Grapevine powdery mildew life cycle. Drawing by R. Sticht. Reproduced with permission from Compendium of Grape Diseases, 1988, American Phytopathological Society, St. Paul, MN. USA.

of *E. necator* biology that a management program can target and, when deployed properly, reduce pesticide inputs while maximizing control.

The disease cycle of *E. necator* spans multiple complete growing seasons (Figure 4). Disease management in the current year will influence disease development in the following year. If incompletely managed in **Year 1**, the fungus will mate and form overwintering structures called chasmothecia (syn. cleistothecia) (Figure 5) on infected fruit and foliage. These structures occur when opposite mating types of the fungus meet and is therefore a function of high disease incidence and severity. Chasmothecia contain ascospores (infectious propagules), which are the result of sexual recombination. This is the only mode of overwintering identified in eastern Washington and is likely the dominant overwintering mode in western Washington. Repeated wetting events from rain, heavy dew, prolonged dense fog, or over-the-canopy irrigation in the late winter/early spring of **Year 2**

Figure 5. The main source of overwintered inoculum (ascospores) in cool and cold climates is cleistothecia. To the naked eye (or 10x magnification), cleistothecia look like small black specks on the upper and lower surfaces of leaves (top). Close up, one can readily see their appendages, which aid in anchoring the fungal body to bark when washed off foliage during fall rains (bottom). Photo courtesy of Michelle Moyer.

weaken the outer walls of the chasmothecia, which causes them to split open and release the ascospores. Ascospores infect developing grape tissue when temperatures are at or above 50°F. A general rule of thumb for predicting potential ascospore infection events is: an infection event has occurred if there is 0.1 inch of rain or more (or overhead irrigation equivalent), and temperatures are above 50°F. Note, however, that this rule does not include heavy dew or prolonged dense fog, which can provide a sufficient wetting duration but cannot be as easily measured as precipitation. Ascospore infections appear as random colonies distributed throughout the vineyard, and they are largely confined to the lower surface of basal leaves.

A second, less common mode of overwintering is via infected dormant buds. In **Year 1**, *E. necator* can infect young, developing buds and remain dormant until the spring of **Year 2** (Figure 4**)**. While most of these infected buds are traditionally removed during dormant pruning, buds that were infected from approximately 6-inch shoot growth until bloom in **Year 1** may be retained in **Year 2**. When shoots emerge from these infected buds in **Year 2**, they are already colonized with powdery mildew hyphae (vegetative growth structures) and are called flagshoots (Figure 6). Flagshoots usually grow poorly and are often distorted, but they serve as a very concentrated source of inoculum within a vineyard. Immediately surrounding locations in the vineyard row will often have heavily infected shoots, clusters, and leaves, complete with shoot and cane scarring (Figure 2). In locations with colder winter temperatures, infected buds are often implicated in reduced bud survival, so vineyards with high disease levels in **Year 1** may have poor primary bud survival in **Year 2**. Bud perenniation (i.e., overwintering) is typically found only in climates with milder winters. This overwintering mode has been reported in western Oregon and may occur in western Washington.

After initial spring infection, *E. necator* will develop and reproduce under a wide range of environmental conditions. In fact, these initial colonies will develop conidiophores (asexual fungal reproductive structures) that will produce one new conidium (asexual equivalent of an ascospore) each day for up to 21 days (Figure 7), even in the absence of wetting events. Although the fungus prefers a relative humidity above 75%, temperatures between 68°F and 85°F, and low levels of solar radiation, it can develop and reproduce under suboptimal condi-

Figure 6. A powdery mildew flagshoot emerging from cane-pruned Vitis vinifera *'Pinot noir.' When buds that develop in Year 1 get infected with powdery mildew, they will overwinter (when not too cold) and emerge as shoots completely covered in powdery mildew in Year 2. Photo courtesy of Walt Mahaffee.*

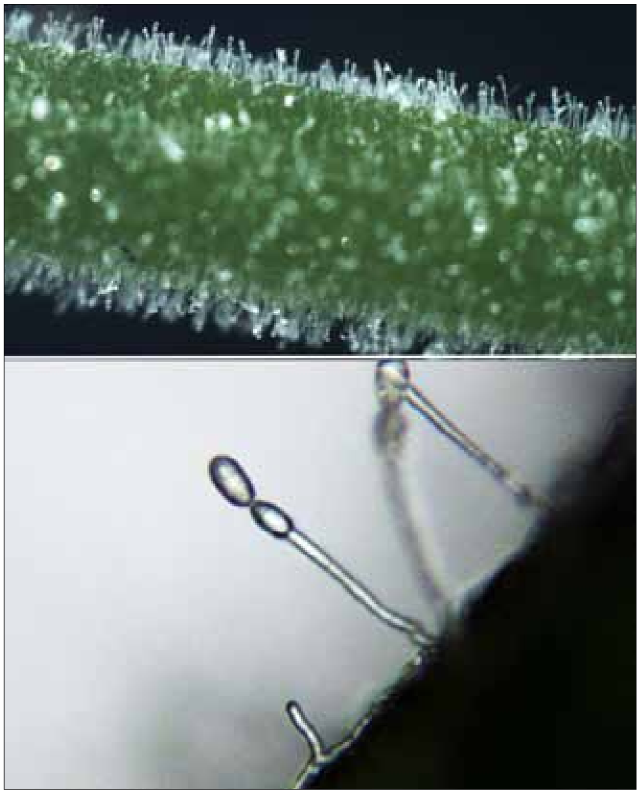

Figure 7. Powdery mildew conidiophores producing conidia on a grape peduncle (top), and a close up of both a sporulating and developing conidiophore (bottom). Photo courtesy of Michelle Moyer.

Figure 8. Grape tissue develops ontogenic (age-related) resistance to Erysiphe necator. *Clusters are susceptible during elongation (top right) and bloom (top left) and then begin to develop resistance on to complete resistance from post-fruit set to véraison. Photo courtesy of Michelle Moyer.*

tions, although at a slower rate. Temperatures below 50°F and above 95°F can debilitate or kill the fungus outright. These environmental conditions should be considered in the context of the interior *canopy* microclimate, which may be significantly cooler and more humid than ambient air, while exposed leaves on the canopy exterior may be significantly warmer. Under optimal conditions, it takes approximately 7 days for the fungus to complete one reproductive generation. This repeating cycle of infection, reproduction, and spread continues until mildew colonies (fungal structures resulting from infection) merge on the grape tissue. When colonies merge, spore production will cease, and chasmothecia will form. This can occur as early as July in western Washington.

Perhaps one of the most significant advances in the understanding of *E. necator* biology is the discovery of ontogenic, or age-related, resistance in grape tissues. This resistance means that tissue becomes less susceptible to infection as it matures (Figure 8). There is a finite window of time in the growing season when fruit (berries and clusters) can be infected—from approximately prebloom (beginning of rachis elongation) to three weeks post-fruit set. In climates with extended and asynchronous bloom, this duration translates into the beginning of earliest rachis elongation to the end of the last cluster to set fruit (within a management block). Of course, there is a transition period between the time of susceptibility and resistance, which can result in diffuse infection of fruit (Figure 9), predisposing it to late-season BBR.

Managing the development of canopy PM is different from managing PM on fruit. This is because of the indeterminate growth of the vine, where new, susceptible foliage is constantly being produced as long as shoots are actively growing. If vegetative growth is not properly controlled, it will result in the continuous production of new, susceptible tissue. In areas that have high summer rainfall or soil with a high water-holding capacity, a combination of drainage tiling and supplemental irrigation (in case drainage becomes excessive) may be needed to increase control over canopy growth and development.

Figure 9. Infections that occur during the transition between susceptible and ontogenic resistance development often result in diffuse powdery mildew colonies, which often kill cells on the epidermis of the berry. These dead cells are prime locations for Botrytis cinerea *infection and the introduction of other secondary spoilage microorganisms. Photo courtesy of Michelle Moyer.*

Cultural Practices for Disease Management

When dealing with fungal diseases like PM, the role of cultural practices in disease management cannot be overemphasized. Cultural management techniques are of great importance in vineyards using reduced input or organic management strategies, or during years of high disease pressure.

Controlling canopy vigor reduces its size and density, thus facilitating air circulation and sunlight penetration, which aids in the control of PM. Quick-fix canopy techniques, such as hedging, that are used when canopy management control is lost can worsen PM epidemics. Repeated or severe hedging can stimulate lateral shoot development creating a denser canopy and providing a source of new, susceptible leaf tissue. Deploying canopy management strategies, such as careful management of spur and shoot spacing, as well as using appropriate devigorating techniques, such as inter-row vegetation for water and nutrient competition, and dividing or extending canopies where appropriate, practicing deficit irrigation, and only applying nutrients (especially nitrogen) as needed will contribute to a strong foundation for disease management.

Canopy manipulation is an additional line of defense in disease management. Fruit-zone leaf removal and shoot thinning are paramount to reducing canopy density because they allow for spray penetration and increase the potential for air circulation and evaporation (reducing humidity). For maximum effect, fruit-zone leaf removal is best done early in the period of peak fruit susceptibility. Waiting too long to implement fruit-zone leaf removal can increase the risk of fruit sunburn. Shoot thinning should be done prior to bloom and should target the removal of non-count shoots.

Fungicide Programs for Powdery Mildew

In order to effectively manage PM, it is important to confirm that PM is the cause of the grapevine disease. Early in the season, suspect white-to-silver foliar spots (colonies) may appear on upper or lower leaf surfaces (Figure 3). As the season progresses, most upper leaf spots will be confined to leaves within the interior of the canopy due to shading. (Suspect white spots on foliage, shoots, or fruit (Figures 1-3) can be observed using a hand lens with a magnification of 10X or higher.) If distinct spider-web like growth attached to the leaf surface is observed, it is likely powdery mildew. Chasmothecia (Figure 5) may also be present. When in doubt, contact your local Regional or Statewide specialist.

Available fungicide options for both conventional and organic production are published annually in the Pest Management Guide for Grapes in Washington or in a more timely fashion on the Internet via the Washington State University Viticulture and Enology website at: http://wine.wsu.edu/research-extension. Contact your local Extension agent or Statewide Specialist for more information, or download the publication from the WSU Extension Publications website. A general list of available fungicides and fungicide groups is provided in Table 1; not all products are registered for use on all grape varieties. Check before using.

When managing PM in the vineyard, you are effectively controlling two different powdery mildew epidemics: one on the canopy and the other on the fruit. Understanding this concept is critical in understanding how to develop an effective spray program. Also, remember that a developing canopy is a changing target—low-volume spray applications (50 gal/acre) can be used in the early season, but higher volume applications may be needed as the canopy develops, in order to get proper coverage.

Early season management. Early season management targets disease control in the developing canopy, since foliar infections are the likely source of PM inoculum for the developing clusters. Primary infection events occur during or slightly after spring rains, when temperatures are 50°F or greater. Rapid shoot development during this time results in a significant

Table 1. Fungicides for grape powdery mildew management in Washington State. This list may change annually, so check the Grape Pest Management Guide for Washington State, Washington State University Publication EB0762.

Trade Names	Active Ingredients	Class	FRAC Group[1]	Mildew Efficacy	Resistance Risk
Abound	azoxystrobin	QoI	11	Good	High
Flint[2]	trifloxystrobin	QoI	11	Excellent	High
Sovran	kresoxim-methyl	QoI	11	Good	High
Pristine[2]	pyraclostrobin[5]	QoI	11	Excellent	High
	boscalid	carboxamide	7		Medium
Adament[2]	tebuconazole	DMI	3	Excellent	Medium
	trifloxystrobin[5]	QoI	11		High
Elite	tebuconazole	DMI	3	Good	Medium
Mettle	tetraconazole	DMI	3	Good	Medium
Quadris Top	difenconazole[5]	DMI	3	Excellent	Medium
	azoxystrobin	QoI	11		High
Procure	triflumizole	DMI	3	Good	Medium
Rally	myclobutanil	DMI	3	Good	Medium
Rubigan	fenarimol	DMI	3	Good	Medium
Inspire Super[2]	difenconazole[5]	DMI	3	Excellent	Medium
	cyprodinil	AP	9		Medium
Luna Experience[2]	fluopyram[4]	SDHI	7	Good	Medium
	tebuconazole	DMI	3		Medium
Unicorn	tebuconazole	DMI	3	Good	Medium
	sulfur[5]	sulfur	M2		Low
Luna Privilege	fluopyram[4]	SDHI	7	Excellent	High
Quintec	quinoxyfen	quinoline	13	Good	Medium
Torino	cyflufenamid	phenylacetamide	U6	Good	Medium
Vivando	metrafenone	benzophenone	U8	Excellent	Medium
Serenade Max[2*,3]	*Bacillus subtilis*	biological	44	Fair	Low
Sonata[2*,3]	*Bacillus pumilis*	biological	44	Fair	Low
Regalia[2*,3]	extract of *Reynoutria sachalinensis*	induced systemic resistance	P5	Fair	Low
Sulfur[3] (*Several formulations*)	sulfur[5]	sulfur	M2	Good	Low
JMS Stylet Oil[2*,3]	narrow-ranged petroleum oil	PDSO	NC	Good	Low
Armicarb or Kaligreen[3]	potassium bicarbonate	carbonate	NC	Fair	Low

[1]Fungicide Resistance Action Committee
[2] Fungicides with dual-purpose use for controlling both *Erysiphe necator* (Powdery Mildew) and *Botrytis cinerea* (Botrytis Bunch Rot). *In some cases, products may have dual-listed control for BBR and PM; however, control of BBR may be an indirect result of controlling PM or diffuse PM, and the product may not be directly active against *Botrytis cinerea*.
[3] Products or various formulations containing these active ingredients are OMRI listed for powdery mildew management. Check OMRI, however, for changes and specific brand recommendations.
[4] Do not use these products on grapes that may be used for purposes other than wine.
[5] These products have varying degrees of phytotoxicity on *Vitis labruscana* 'Concord,' or on certain interspecific hybrids.

percentage of the canopy developing *after* the most recent fungicide application, leaving it unprotected against future infection. Fungicide programs should be deployed based on the rate of shoot development, the levels of potential overwintering inoculum, and immediate past and future environmental conditions that favor disease development.

Rachis elongation to three weeks post-fruit set. This is the most critical time for managing disease on clusters. This period of peak susceptibility typically corresponds with optimal PM weather conditions in western Washington. If weather conditions are suitable for fungal development, spray intervals should be tight (on the shorter end of labeled duration), and the use of the most effective products available (with proper fungicide rotation) is recommended. In years where weather conditions can delay plant development, thus keeping susceptible tissue exposed for a longer period of time, this practice is especially important.

Post-fruit set to harvest. During this time, applications for PM control are directed at managing canopy disease levels, if warranted. Since fungicide applications during this time are occurring when there is an increased likelihood of existing infections, the use of fungicides that are at high risk for developing resistance are discouraged (see the section on Management of Fungicide Resistance Development below).

Effective management of canopy PM reduces the chances of chasmothecia formation. In areas with a delayed first frost, the use of fungicides, such as refined petroleum oils and bicarbonates, before leaf-fall may disrupt the development of chasmothecia, thus reducing inoculum carryover into the following year.

Management of Fungicide Resistance Development

Erysiphe necator has developed resistance to many commonly used fungicides in various parts of the world. This resistance development is accelerated when proper resistance management guidelines are not followed. Always follow label instructions, which indicate the maximum applications per site/year and the number of sequential applications of the same product chemistry. The Fungicide Resistance Action Committee (FRAC) (http://www.frac.org) has developed general guidelines for fungicide resistance management and has divided fungicide classes into numbered groups based on mode of action and resistance risk. A product's FRAC Group number, or numbers, often appears on the product label.

General resistance management guidelines include the incorporation of cultural practices (e.g., leaf removal, shoot thinning, and vigor management) that lower disease pressure. The incorporation of these practices serves to reduce resistance development in pathogen populations. Always use fungicides in a protective, rather than reactive, manner. It is far easier to prevent PM than to cure it.

Additional guidelines include limiting the number of applications of individual modes of action (specific compounds within a FRAC group) per season and limiting sequential applications of these same modes of action. Do not tank mix or alternate fungicides with the same FRAC Group number in a spray program (examples are given in Table 1). It is preferable to use only one application of any resistance-prone compound, and then switching to a fungicide from a different mode of action class or FRAC Group. Medium risk compounds, such as the DMIs (Group 3) and quinoline (Group 13) should be applied no more than three times per season and no more than twice in sequence. High risk QoI compounds (Group 11) or premixed formulations containing them (Adament, Flint, Sovran, Quadris Top, Pristine, and Abound) should be alternated 1:1 with other modes of action or groups. ***Never*** use more than two QoI applications in sequence. If two sequential applications of a QoI fungicide are used, follow this treatment sequence with at least two applications of one or more fungicides with a different mode of action or FRAC Group. Sulfur is a relatively inexpensive and effective companion product for mixing with medium- or high-risk compounds. Try to include it in every spray tank aimed at PM, if permitted by the use instructions on the product label. Always follow label instructions for application rates and intervals, use a properly calibrated sprayer, and ensure sufficient spray volume to provide good coverage.

The most critical period for PM control is from immediate prebloom up to three weeks post fruit-set. The most effective compounds should be used during this period. Bloom is also a critical period in the establishment of BBR in the vineyard. As noted earlier, several highly effective PM fungicides/fungicide premixes (Adament, Flint, Inspire Super, Luna Experience, and Pristine) act against *both* PM and BBR, when used at appropriate rates. These compounds are logically used during bloom, but remember to keep applications of QoI (Group 11) compounds, or mixtures containing them, to a minimum.

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Use pesticides with care. Apply them only to plants, animals, or sites as listed on the label. When mixing and applying pesticides, follow all label precautions to protect yourself and others around you. It is a violation of the law to disregard label directions. If pesticides are spilled on skin or clothing, remove clothing and wash skin thoroughly. Store pesticides in their original containers and keep them out of the reach of children, pets, and livestock.

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