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Integrated Pest Management for Powdery Mildew of Grapes in Arizona

Matt Halldorson and Jiahuai Hu

Introduction

Due to its ubiquitous nature and prolific reproduction potential, powdery mildew (PM) is arguably the most economically important disease of wine and table grapes in many parts of the world. The pathogen that is responsible for this disease, *Erysyphe necator* (Schw.) Burr. (synonym *Uncinula necator*) is a fungus, which if not held in check by chemical and/or cultural intervention, can compromise fruit quality and quantity in the vineyard. Although cultural practices such as shoot thinning and proper irrigation management are key to limiting infections, in most cases without the use of fungicides, PM would likely be responsible for greater losses than any other single pathogen of grapes, worldwide (Moyer and O'Neal, 2013, Pearson and Goheen, 2009). The disease was first described in North America (where it is believed to have evolved with North American Vitis species) in the early 19th century and was later observed in Europe, outside its native range (Gadoury et al., 2011). The introduction of PM caused severe crop losses in European wine grapes (*Vitis vinifera* L.), which were highly susceptible to the disease, and it was not long before the vast majority of grape growers in France were applying regular anti-microbial sulfur or copper treatments in order to keep the disease at bay. While the advancements in agricultural chemistry have led to greater consistency with regard to yields and quality, there are risks associated with the use of fungicides to the vineyard workforce, beneficial organisms of the vineyard, and the chemical's own long-term efficacy due to the development of resistant strains of the fungus. These factors bring to the forefront the need to thoroughly understand the biology and disease ecology of E. necator, so that growers can develop an integrated pest management program that is not overly reliant on pesticides alone. In 2022, the University of Arizona conducted a Statewide Commercial Viticulture Needs Assessment to better understand the priorities of grape growers (Halldorson, et al, 2024). The results stated that "Disease Management" was the third highest priority for growers with regard to Extension programming, and PM specifically was rated as the disease of greatest concern. While powdery mildew undoubtedly can be a problem in Arizona vineyards, the state's unique precipitation pattern, coupled with high ambient temperatures and light intensity creates a unique management scenario.

Disease and Pathogen

Erysyphe necator is an obligate biotroph (it must obtain its nutrients from a living source) that reproduces in a polycyclic manner (Figure 1), which can lead to infections that are not detected until they have become a significant problem in the vineyard. Mature chasmothecia (the fungal fruiting bodies, formerly called cleistothecia, Figure 2) are displaced by winter rains from where they formed (on the green tissues of the vines) the previous growing season and are deposited in the vine's bark or soil below (Gadoury and Pearson, 1988). In the following spring, when environmental conditions are favorable (average temperatures exceeding 50°F and a precipitation event, leaf-wetting irrigation, or sufficient dewpoint that deposits more than 0.1 inches of water), chasmothecia swell, break open and release ascospores,

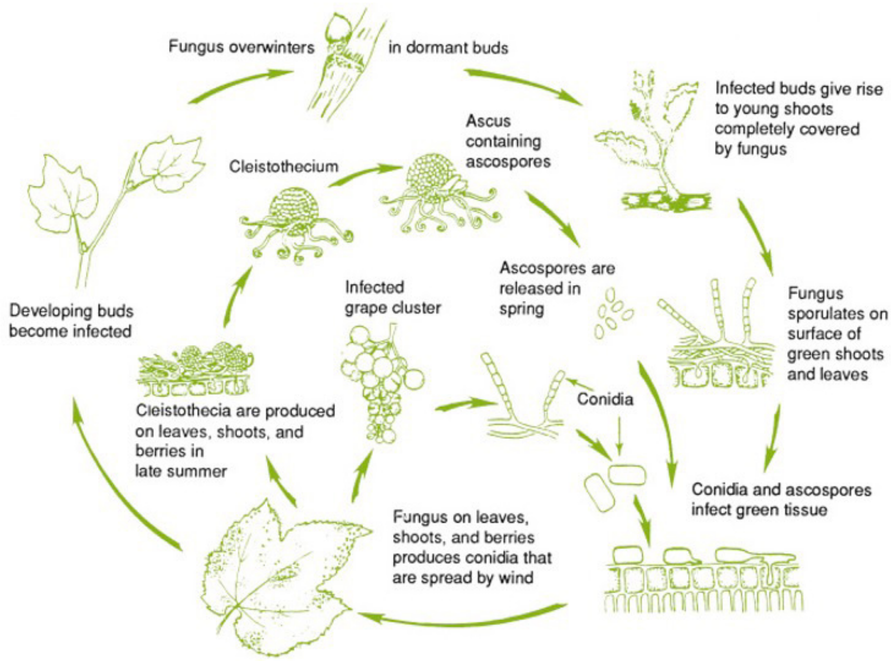

Figure 1. Modified from original drawing by R. Sticht (Kohlage), from Pearson and Goheen, 2009.

Figure 2. Mature chasmothecia (formerly cleistothecia), the small, dark sexually reproductive survival structure of *E. necator*, formed on a leaf, most likely prior to deposition due to precipitation (photo: University of Georgia Plant Pathology, University of Georgia, Bugwood.org).

the sexual spores formed by genetic recombination (Moyer and O'Neal, 2013). This is referred to as a "primary infection event". If an ascospore lands on green Vitis tissue, it will germinate (regardless of leaf wetness), attempt to attach itself, and penetrate the host's cell wall (Gee et al., 2000, Micali et al., 2008). If attachment and penetration are successful, the fungus begins withdrawing nutrients and other resources from the grapevine without damaging the host's cell membrane. This extraction is not limited to the plant cell in direct contact with the fungus, as nutrients throughout the host are mobilized to the site of attack. Upon a successful infection, the fungus will spread out on the plant's surface in the form of hyphal colonies (the white/silver fuzz most often seen on leaves and fruit), using the vine's resources to expand the hyphal network and initiate a secondary infection cycle referred to as "dispersal".

Temperatures ranging between 50°F and 95°F are required for the proliferation of the secondary infection cycle, though E. necator prefers temperatures that are regularly between 68°F and 85°F, relative humidity above 75% (free liquid water, however, is not ideal) and low levels of direct solar radiation (Moyer and O'Neal, 2013). Dispersal involves the production of structures called conidiophores, which produce asexual spores called conidia and grow perpendicular to the powdery hyphal growth that covers the leaf surface. The mechanism for dispersal is passive, requiring mechanical pressure, wind, or convection currents. Upon landing on a suitable host, conidia germinate and begin the dispersal cycle once again (Glawe, 2008). It is also possible for E. necator to overwinter within dormant buds if those buds were infected while susceptible (4 to 6 weeks after bud break) in the prior year. When these infected buds break open, the shoot tissue is often deformed and covered with *E. necator* hyphae (Figure 3). These stunted shoots are referred to as "flag shoots", which can presumably release conidia before a primary infection event. It is unknown how often these flag shoots are observed in Arizona vineyards, so the importance of a robust scouting program, especially in the spring cannot be over-emphasized.

The cycle begins again when chasmothecia form due to environmental conditions becoming unfavorable (low relative humidity, high levels of UV light, temperatures above 95°F, or plant tissue resistance) or at the point where an infection becomes severe enough that compatible mating types converge on the same tissue (Gadoury et al., 2011). Generally, chasmothecia are believed to then overwinter in the bark of the vine, though in warm areas where fall temperatures are mild such as southern Australia or the Mediterranean climates of Italy, it is possible for them to form by mid-summer, causing a second ascospore release and subsequent primary infection event within the same season (Gee, et al., 2000). It is unknown whether or not the vineyards of Arizona experience multiple generations of chasmothecia and ascospore release.

Signs and Symptoms

Due to the microscopic nature of the spores, symptoms of PM usually go undetected until they become more advanced. It is at this time that hyphal spread (the "powder") and the dispersal cycle begins (Figures 4 and 5). This is characterized by a shiny white or silver sheen (hyphae and conidiophores), though initial symptoms may appear as chlorotic spots which are challenging to diagnose. If the disease is allowed to progress, severe infections left unchecked can lead to the destruction of tissues and compromised fruit quality. Further, an infection by *E. necator* can leave fruit highly susceptible to infection by weaker pathogens such as *Botrytis* cinerea or the sour rot disease complex (fruit flies, yeasts and acetic acid-producing bacteria). Old infections are marked by "scarring" of the tissue (especially canes), which may

Figure 3. Flag shoots are a phenomenon where wine grape shoots will emerge from the bud displaying a powdery mildew infection. Photo: Walt Mahaffee, Oregon State University.

Figure 4. Grape leaf with hyphal infection by *E. necator* (photo: Gerald Holmes, Strawberry Center, Cal Poly San Luis Obispo, Bugwood.org).

Figure 5. Powdery mildew infection on a grape cluster (photo: Julie Beale, University of Kentucky, Bugwood.org).

appear as a spider web-like pattern in minor infections or large splotchy patterns in more severe cases (Figure 6). Due to the pathogenic and destructive nature of *E. necator,* severe foliar infection may reduce the photosynthetic capacity of the plant and the ripening of fruit, while also compromising the winter hardiness of vines in applicable areas.

Integrated Pest Management in the Vineyard

Cultural Practices

Although some cultivars seem to be more susceptible to powdery mildew than others, complete resistance is uncommon amongst most cultivars of *Vitis vinifera*. The severity of a powdery mildew infection is highly dependent upon the environmental conditions, the inoculum level of the pathogen, and the phenological stage of the host. While the ambient macro and meso-climate conditions are generally those that are considered when reviewing the daily weather reports, the most important environmental conditions that influence disease development happen at the microclimate level. Within a vigorously growing grapevine canopy, temperatures are cooler and humidity levels higher than the area just outside of the canopy. This is due to plant transpiration (water evaporating from the leaf surface), the shaded nature of the canopy, and the vineyard's physical ability to block the wind. Wine and table grape growers can manipulate canopy microclimate with cultural practices such as shoot-thinning and leaf removal, both of which open up canopies and expose their interiors to sunlight, heat, and ventilation (which lowers microclimate humidity). These practices may also facilitate effective spray coverage of applied fungicides. In areas where possible, irrigation management is also key to controlling canopy growth and transpiration rates. If an infection does occur, unfavorable environmental conditions will also drive the transition from dispersal (conidia spore release) to survival (chasmothecia initiation).

Fungicide Use

In some cases, cultural practices alone may be enough to deter grape PM epidemics, but due to the potential for crop loss, most growers worldwide rely on the use of chemical cover sprays in order to reduce infections. Historically, sulfur, copper, and mineral oils have been used successfully due to the fact that they possess prophylactic qualities as well as the ability to eradicate mild infections. However, these products required frequent re-application in the face of high disease pressure, and the 20th century introduced the broad use of synthetic fungicides. These products are largely prophylactic and sometimes systemic (will move through plant tissues internally and with the plant as it grows, to some extent), allowing growers to stretch out spray application intervals. While sulfur is still used today (often in early season and organic production scenarios),

Figure 6. "Scaring" on cane and shoot tissue due to hyphal infection of *E. necator* (photo: University of Georgia Plant Pathology, University of Georgia, Bugwood.org).

modern fungicide programs are often dominated by the use of synthetic fungicides which interfere with the metabolism of the pathogen, often impacting its ability to germinate or proliferate hyphae.

A successful fungicide program begins before a primary infection event, relying on prevention and not eradication. After a primary ascospore-infection event (described above), it must be assumed that E. necator spores are present, and it is advised that growers use a registered fungicide at an interval that is appropriate for the level of pressure in the vineyard. Developing fruit clusters are most susceptible between approximately 3" of shoot growth (when inflorescences are initially exposed) and 3 to 4 weeks post fruit set (pea-sized berries) (Moyer and Grove, 2012, Ficke et al, 2002). This being said, berries in a single cluster develop asynchronously, and many growers will continue prophylactic applications until the onset of ripening or veraison, when the susceptibility threshold is more evident. After this period, there is no need to continue to treat the fruit, as it has acquired resistance to the pathogen (see ontogenic resistance below). Any new tissue, however (such as continued primary or lateral shoot growth), will continue to be susceptible to *E. necator*, so it is ideal to irrigate appropriately in order to avoid an actively growing canopy after veraison.

In addition to canopy management and fungicide use, an understanding of grapevine biology is key to avoiding infection. While it was previously believed that grape berries become resistant to PM at a specific Brix (percent sugar in the berries) or at veraison, it is now widely accepted that host resistance is ontogenic, or "age-related". Ontogenic resistance is the phenomenon by which plant tissues, as they mature, acquire resistance to infection by *E. necator* (Gadoury et al., 2011). Though the mechanisms are poorly understood, it is believed that plant resistance is acquired as tissues age, potentially through the development of preformed or physical biochemical barriers or the inducible synthesis of antifungal chemicals. In the case of berries, this resistance is believed to be acquired as early as 4 weeks past fruit set. However, rachis tissue does not readily acquire ontogenic resistance. Growers are advised to slow canopy growth after veraison, in order to halt the creation of new, susceptible tissue.

Chemical Resistance Management

Due to high reproductive rates, its ability to infect under a wide range of climatic conditions, and its easy dispersal by air currents, E. necator has the propensity to develop resistance to many site-specific fungicides, rendering the products less effective. Selection for resistant populations occurs when a site-specific product is:

1. Used at below lethal application rates
2. Used repeatedly in sequence
3. Used numerous, non-sequential times in a season

There is probably already some resistance to a specific chemical mode of action among natural PM populations, and those individuals tend to survive after the application of that specific chemical. If a different chemistry is used at its maximum labeled rate during the next fungicide application, this small resistant sub-population is killed, and any resistance issue is most likely avoided. However, if the same chemistry is used repeatedly, the resistant sub-population is allowed to proliferate until the overall population is dominated by resistant individuals. This resistance effectively mutes the efficacy of the fungicide, giving growers one less tool to control disease. In order to combat this phenomenon, the Fungicide Resistance Action Committee (FRAC) has classified each product by its mode of action, which describes the biochemical process that is impacted by a product. These groups are represented by simple codes that separate chemical active

Trade Name	Chemical Name	Class	FRAC Group
Rally 40WSP	myclobutanil	demethylation inhibitor (DMI)	3
Procure 480SC	triflumizole	demethylation inhibitor (DMI)	3
Quadris Top	difenoconazole & azoxystrobin	Demethylation inhibitor (DMI)/ quinone outside inhibitor (QoI)	3 & 11
Endura	boscalid	Succinate dehydrogenase inhibitor (SDHI)	7
Quintec	quinoxyfen	azanapthalene (quinoline)	13
Serenade Max	Bacillus subtilis	biological	44
Several formulations	sulfur	inorganic	M2
Vivando	metrafenone	aryl-phenylketone	50
Gatten	flutianil	thiazolidine	U1
JMS Stylet Oil	mineral oil	oil	Not Classified

Table 1. A non-exhaustive list of various fungicides labeled for Erisiphe necator and their corresponding chemical names, class of compound, and Fungicide Resistance Action Committee (FRAC) group number or code. Notice that trade and chemical names can be different, but share FRAC codes, inferring that their modes of action against E. necator are functionally similar. Products that have multiple FRAC codes are "pre-mixed" which may be done to further combat fungicide resistance. The use of these particular products in this publication does not imply endorsement by the authors nor criticism of other products.

ingredients based on mode of action (Table 1). In order to limit the risk of pesticide resistance development, these groups should be rotated regularly throughout the season, while also avoiding overuse within a season, and/or low application rate treatments that some individuals may be able to survive. There is no known resistance to sulfur or mineral oil products, though care must be taken not to apply them at high temperatures.

Due to the fact that Arizona has a unique climate in terms of precipitation patterns, heat accumulation and relative humidity, management of PM may be slightly different than in other growing regions. Typically, chasmothecia release ascospores in spring, when environmental conditions are favorable (as stated above), but Arizona is not generally characterized by wet spring events, and in some years, the region must wait until summer to experience significant precipitation, post-winter (Figure 7). Because of this, it may be possible for Arizona grape growers to hold-off on their initial fungicide applications, if they don't experience the favorable environmental conditions necessary for a primary infection event. This being said, enough moisture from the deposition of dew can also trigger an infection event and growers must be confident that they can cover their vineyard with an approved fungicide before a significant spring rain event. Temperatures above 95°F truncate infections and begin to kill the fungus, so if a vineyard has remained clean, once the summer heat has set in, it is unlikely that a secondary infection will proliferate. However, once the summer monsoon rains begin, cooling down temperatures and raising the relative humidity, there is potential for a latent secondary infection to begin on any actively growing tissues, or potentially a primary infection event. By using their understanding of vineyard microclimate, proper fungicide management, and ontogenic resistance, growers can use cultural and chemical techniques more effectively in the ongoing battle against powdery mildew of grapes

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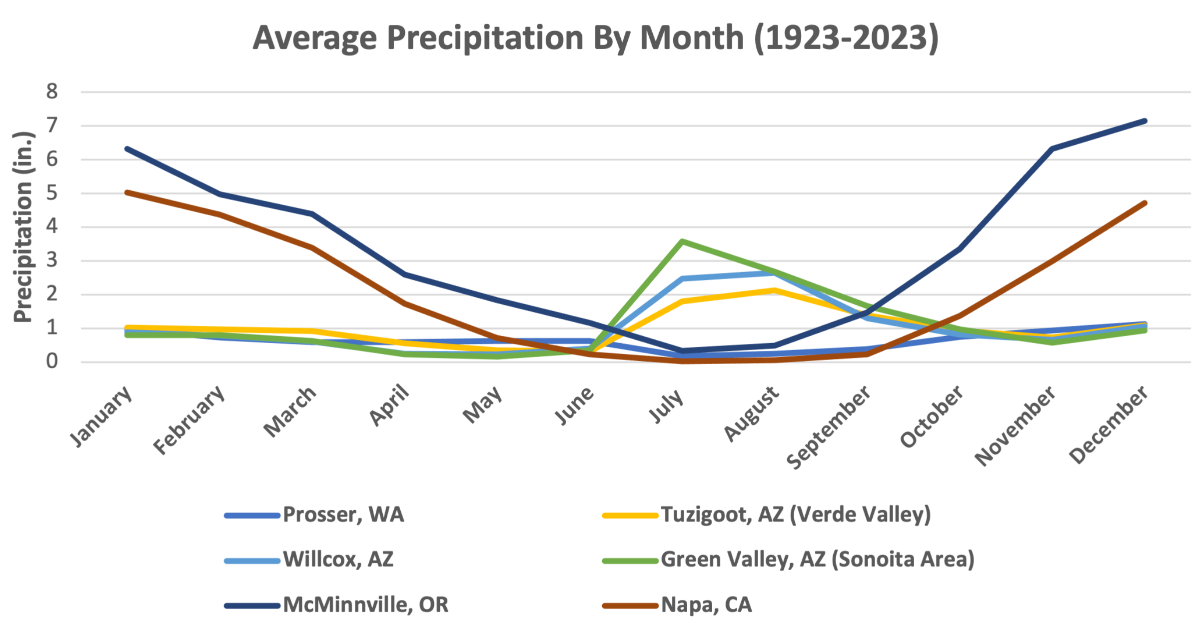

Figure 7. Average precipitation by sites in Arizona, California, Oregon, and Washington state. Arizona's precipitation pattern is dominated by the monsoon, receiving significant precipitation during the summer months, and experiencing a relatively dry spring (National Weather Service Data).

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THE UNIVERSITY OF ARIZONA
Cooperative Extension

AUTHORS

Matt Halldorson
Yavapai County Director, Associate Agent - Agriculture and Natural Resources, Area Agent - Viticulture

Jiahuai Hu
Associate Professor, Plant Pathology

CONTACT
Matt Halldorson
mmhalldorson@arizona.edu

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