Introduction and significance
Powdery mildew has been an important foliar disease of both nursery and fruit production strawberry crops in California for a long time. It is a serious disease and if not managed properly can result in significant yield reductions. While powdery mildew is most severe on strawberry grown along the more humid coast of California, the disease can occur anywhere the crop is grown in the state and beyond.

Symptoms and Signs
Powdery mildew can develop on leaves, flowers, and fruit. The disease generally first appears on foliage, with the undersides of younger leaves exhibiting small, irregular white patches of fluffy mycelium (Figure 1). Because of the many white hairs on the undersides of strawberry leaves, early colonies could be overlooked. As the mildew continues to develop and cover more of the leaf undersurface, the leaves curl upwards which is an important diagnostic symptom (Figure 2). As mildew colonies age, the underlying leaf tissue can become extensively colonized and turn purple to red in color (Figure 3). With time, powdery mildew colonies can also develop on the upper leaf surface and cause red, purple, or brown blotches on cultivars such as ‘Camarosa’. Fully expanded, mature healthy leaves are rarely colonized by mildew since the fungus prefers younger tissue.

Mildew spores produced on leaves are spread in air currents and can land on flowers, which may lead to deformed flowers that fail to develop properly and are covered with mycelial growth. Spores can also land on and colonize immature fruit, resulting in irregularly shaped fruit, irregular ripening, discolored patches on the otherwise green tissue, and fruit covered with white mycelium (Figure 4). Flower and fruit infections can result in direct yield losses.
At 10 to 15 days after bloom (when the fruit receptacle turns pink or red) fruit tissues that have escaped colonization are apparently immune from infection, though the “seeds” (achenes) can still be colonized (Figure 5). Tissues of such fruit shrink, causing the achenes to protrude, giving the fruit a “seedy” appearance and coarse texture. Such fruit can have a distinctive moldy flavor.

Causal Organism
Powdery mildew is caused by the fungus *Podosphaera aphanis* (previously named *Sphaerotheca macularis f. sp. fragariae*). *Podosphaera aphanis* has a narrow host range and apparently only infects cultivated and wild strawberry species. Like most powdery mildews, the majority of the mycelium grows on the outside of strawberry tissues. Spores are barrel shaped, whitish to clear, and form distinctive chains (Figure 6). Since these spores are relatively large, it is possible to see the chains of spores with a low power (20X) hand lens. These spores, also called conidia, represent the asexual phase of the pathogen and are the most abundant spore type produced. *Podosphaera aphanis* also forms a second type of spore, called the ascospore, that is the sexual phase of the organism. Ascospores form inside tiny, spherical, brown structures called chasmothecia (previously called cleistothecia). This chasmothecium/ascospore phase allows the fungus to genetically recombine and form new strains. Chasmothecia are resilient to unfavorable environmental conditions and allow the pathogen to overwinter and survive in the absence of living plant tissue. Chasmothecia have been only rarely observed on strawberry in California.

Disease Cycle
Because powdery mildew is common in field nurseries, it is likely that the majority of primary inoculum infecting first-year plantings comes from the transplants. Plant leaves and stems may come already infected, or plant buds and crowns could be colonized by or contaminated with the fungus. In addition, second-year or volunteer strawberries in production areas are likely to be infected with powdery mildew; these established plants provide another source of primary inoculum for newly planted, first-year strawberry. In other states, researchers have demonstrated that ascospores released from the chasmothecia function as a source of primary inoculum that initiates the disease. While this part of the disease cycle has not been verified for California fields, it is possible that ascospores may also play a role as primary inoculum here.

Once powdery mildew starts colonizing the new leaves, large numbers of spores are produced and spread via winds to other leaves as well as flowers and fruit. Disease is favored by high (greater than 75%) relative humidity and moderate temperatures of 60° to 80° F (15° to 27° C). However, free moisture on leaves from dew, rain, or overhead irrigation inhibits powdery mildew development. When strawberry plants are grown inside greenhouses or plastic tunnels, powdery mildew can be more severe due to lower light intensity, reduced UV radiation, absence of leaf wetness, and elevated humidity levels.
Management

1. Select resistant or tolerant cultivars. Growing strawberry cultivars that are genetically resistant to powdery mildew is the first and best means of combatting the disease. Unfortunately, there are no commercially available cultivars completely resistant to *P. aphanis*. However, field observations and research studies have demonstrated that strawberry cultivars exhibit different levels of susceptibility to powdery mildew. Cultivars such as ‘Seascape,’ ‘Chandler,’ ‘Albion,’ ‘Florida Radiance,’ ‘Sweet Ann,’ and ‘San Andreas’ have partial field resistance, while ‘Camarosa,’ ‘Ventana,’ and ‘Monterey’ are more susceptible. If particular ranches or areas have a history of severe powdery mildew, growers should consider planting partially resistant cultivars. Also, growers should consider using a partially resistant cultivar if planting adjacent to a second year strawberry field.

2. Plant disease-free transplants. Since initial inoculum comes from the transplants, powdery mildew management programs should be in place during transplant production. Such programs typically involve the application many fungicide sprays. To minimize the development of fungicide-resistant powdery mildew, single-site active fungicides that are used in the nursery should be different from those used in fruit production fields.

3. Effective use of fungicides. Fungicides are a key component for minimizing powdery mildew for transplant production and fruit production operations. There are a number of materials available for use on strawberry. Table 1 (Fungicides for Powdery Mildew on Strawberry) lists some registered materials for strawberry and is arranged with fungicides having greater efficacy at the top. List order is based on several years of fungicide efficacy field studies and observations and experiences of growers and pest control advisors. For additional information on powdery mildew fungicides see [http://www.ipm.ucdavis.edu/PMG/r734100711.html](http://www.ipm.ucdavis.edu/PMG/r734100711.html).

![Figure 6. The powdery mildew pathogen produces large numbers of spores that are produced in chains and later spread in the air.](image)

<table>
<thead>
<tr>
<th>Product</th>
<th>Active Ingredient</th>
<th>Mode of Action</th>
<th>FRAC1 group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Merivon</td>
<td>Fluxapyroxad + Pyraclostrobin</td>
<td>Complex II in fungal respiration + Quinone outside inhibitor</td>
<td>7 + 11</td>
</tr>
<tr>
<td>Torino</td>
<td>Cyflufenamid</td>
<td>Unknown</td>
<td>U6</td>
</tr>
<tr>
<td>Micronized sulfur</td>
<td>Sulfur</td>
<td>Multi-site inorganic</td>
<td>M2</td>
</tr>
<tr>
<td>Pristine</td>
<td>Boscalid + Pyraclostrobin</td>
<td>Complex II in fungal respiration + Quinone outside inhibitor</td>
<td>7 + 11</td>
</tr>
<tr>
<td>Abound</td>
<td>Azoxystrobin</td>
<td>Quinone outside inhibitor</td>
<td>11</td>
</tr>
<tr>
<td>Quintec</td>
<td>Quinoxyfen</td>
<td>G-proteins in early cell signaling (proposed)</td>
<td>13</td>
</tr>
<tr>
<td>Rally 40 W</td>
<td>Myclobutanil</td>
<td>Demethylation inhibitor</td>
<td>3</td>
</tr>
<tr>
<td>Procure</td>
<td>Triflumizole</td>
<td>Demethylation inhibitor</td>
<td>3</td>
</tr>
<tr>
<td>M-Pede</td>
<td>Potassium salts of fatty acids</td>
<td>Soap</td>
<td>Not applicable</td>
</tr>
</tbody>
</table>

1 FRAC = Fungicide Resistance Action Committee

Notes: Products are arranged with fungicides having greater efficacy at the top of the list. Not all registered fungicides are listed. It is recommended to not make more than two sequential applications of fungicides in the same fungicide grouping. Before using any of these fungicides, consult product labels for current status of product registration, restrictions, and use information and check with your local Agricultural Commissioner’s office in the need of clarification. Be aware of Maximum Residue Levels (MRLs) for target market before use.
As with many fungicides, there are concerns that repeated use of products could result in powdery mildew strains that have reduced sensitivity to those products. While not yet documented in California, reduced effectiveness of demethylation-inhibiting (DMI) fungicides (FRAC Group 3) for control of powdery mildew on strawberry has been found in other growing regions. Therefore, it is critical to implement spray programs that use products having different modes of action. The possibility of powdery mildew isolates developing resistance to fungicides also argues for an integrated program that would minimize the use of the same fungicides being used at transplant and fruit production operations as this increases selection pressure and increases the likelihood of resistance development.

Integrating sulfur into spray programs at transplant and fruit production fields is a useful resistance management strategy because sulfur is a multi-site inhibitor, to which resistance has not developed. Sulfur is strictly a protectant material and is most effective if applied prior to powdery mildew establishment. A number of horticultural oils (such as Golden Pest Spray Oil) and insecticidal soaps (M-Pede) are also effective in controlling powdery mildew when applied at a frequency of every 10 to 14 days. However, frequent applications of these oils or soaps will stress strawberry plants and reduce their productivity.

To maximize the efficacy of fungicides, one should begin applications when symptoms and signs first occur. For organic strawberry production, growers can use sulfur, oils, and bicarbonates. It is important to note that none of these materials should be mixed together in the same tank. Before using any fungicides, check with your local Agricultural Commissioner’s office and consult product labels for current status of product registration, restrictions, and use information.

References


