Evaluating Fungicide Programs for Apple Powdery Mildew – Summary of 1st Year Data from Geneva NYSAES

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The appearance of scab resistance to the SI fungicides has raised concerns regarding SI resistance in powdery mildew control. Our research has shown that application at the usual periods of infection for the disease at 'bloom', 'petal fall', and '1st cover' appear to be most important for managing powdery mildew. Of the fungicides, the SIs, strobilurins, and carboxamides provided the best mildew control when applied at petal fall and first cover. Performance of fungicide programs for mildew control appears to be diminished when an EDBC protectant is used at 'petal fall' or '1st cover' instead of an SI, strobilurin, or carboxamide.

Compared to apple scab and fire blight, powdery mildew is not a devastating diseases of apples in the Eastern United States. However, the disease can cause serious problems on several economically important apple cultivars including 'Cortland', 'Idared', 'Gingergold', and 'Jonagold' to name a few. Symptoms of infection include a powdery white blight of young leaves and shoots along with fruit russetting. Severe mildew infections can lead to reduced yields from aborted blossoms, poor return bloom, and compromised shoot growth. Powdery mildew infection can occur in the absence of free moisture, hence the disease can even be a problem in dry seasons such as we are currently experiencing in New York.

Apple powdery mildew is typically managed by fungicide programs designed for apple scab, as infection periods and susceptible phenological stages for both diseases often overlap. The sterol biosynthesis inhibitor (SI) fungicides have excellent activity against powdery mildew, and the widespread use of SIs in apple scab fungicide programs in New York has likely kept powdery mildew in check. However, reports of SI resistance in NY apple scab populations have also raised concerns regarding SI resistance in mildew populations. It has been suggested that SI applications at lower label rates are becoming insufficient to control mildew in NY. However, there have been no documented control failures using the SI fungicides.

Should SI resistance in NY apple scab populations become more prevalent, fungicide management programs for apple scab may no longer include these effective mildewcides. If growers with SI resistant apple scab populations were to switch to a full protectant program of ethylenebisdithiocarbamates (EDBC)s and Captan applications, powdery mildew may become a larger problem as these fungicides have no effect against the disease. In these situations, growers would still need to make SI, sulfur, or strobilurin applications in order to manage powdery mildew.

Primary Objective. New experimental apple scab fungicides will be introduced into the pesticide market in the near future. Several of these materials are SI fungicides that were previously not labeled for apples in the United States, but still show promise in SI resistant orchards in NY. The primary objective of this work is to establish protocols which can be consistently used to evaluate the efficacy of upcoming apple scab fungicide programs for powdery mildew control. The resulting data from this year's evaluations and that of subsequent years will be used to establish future recommendations as to the best timing and materials for managing apple powdery mildew.

Field Trial Design

Two field trials were set up at two orchard sites at the New York State Agricultural Experiment Station (NYSAES). At each orchard, 23 and 24 fungicide programs were evaluated for powdery mildew control on different mildew-susceptible cultivars. At one of the orchard sites, two different powdery mildew rating schemes were compared with one another.

Test Orchards. The orchard sites for the trials were located at research farms of the New York State Agricultural Experiment Station in Geneva NY. The Darrow site consisted of paired tree plots of mature (>30 years of age) 'McIntosh' and 'Cortland' scion on MM.106 rootstocks. The 'Cortland' trees consistently develop mildew infections each season. The orchard also has a history of considerable SI and strobilurin fungicide use, and is known to have a DMI resistant apple scab population. The presence of an SI resistant scab population makes this experimental orchard an ideal site for evaluating fungicide programs for scab resistant orchards or orchards exposed to strong selective pressures for SI resistance.

TABLE 1

Fungicide programs implemented at the Darrow farm on 'Cortland' apples in 2007[a]

	Application Schedule				
Fungicide Program	April 28 (Green Tip – Half inch Green)	May 4 (Half inch Green – Tight Cluster)	May 11 (Pink – Bloom)	May 18 (Bloom – Petal Fall)	May 29 (1st Cover)
	Check Programs				
Untreated	No application	No application	No application	No application	No application
Protectant Program	EBDC	EBDC &/or Captan	EBDC &/or Captan	EBDC &/or Captan	EBDC &/or Captan
	Sterol Biosynthesis Inhibitor Programs				
SI: Bloom - 1C[b]	EBDC	EBDC & Captan	SI	SI	SI
SI: Petal Fall -1C	EBDC	EBDC & Captan	EBDC & Captan	SI	SI
SI+EBDC: Bloom - 1C	EBDC	EBDC & Captan	EBDC & SI	EBDC & SI	EBDC & SI
SI+EBDC: Petal Fall -1C	EBDC	EBDC & Captan	EBDC & Captan	EBDC & SI	EBDC & SI
	Strobilurin Programs				
Stroby: Bloom - 1C	EBDC	Stroby	Stroby	EBDC & Captan	Stroby
Stroby: Petal Fall -1C	EBDC	EBDC & Captan	EBDC & Captan	Stroby	Stroby
	Anilinopyrimidine Programs				
AP: Bloom - 1C	EBDC	AP	AP	EBDC & Captan	AP
AP: w/SI Petal Fall -1C	EBDC	AP	AP	SI	SI
	Carboxamide Programs				
Carboxamide: Bloom - 1C	EBDC	EBDC & Captan	Carboxamide	Carboxamide	Carboxamide
Carboxamide & EBDC: Bloom - 1C	EBDC	EBDC & Captan	Carboxamide & EBDC	Carboxamide & EBDC	Carboxamide & EBDC

[a]Fungicide abreviations are as follows: EBDC = ethylenebisdithiocarbamate, SI = sterol biosynthesis inhibitor, Stroby = strobilurin, and AP = anilinopyrimidine
[b]'1C is First Cover

The Reseach South site consisted of paired tree plots of young (12 year old) 'Jonagold' and 'Empire' scion on MM.111 rootstocks with M.9 interstems. Within the paired tree plots, the 'Jonagold' trees have consistently developed severe mildew infections over the last few years. The combination of the orchard age, strong mildew pressure, and a mildew susceptible cultivar make this research orchard suitable for mildew fungicide evaluations.

Fungicide programs. Fungicide programs at each orchard were designed to manage both scab and mildew with applications timed to the major apple scab infection periods, similar to fungicide programs practiced by apple growers during the early season. Both locations included standard untreated and protectant programs consisting of: half-rate EDBC applications alone, Captan applications alone, and half-rate EBDC with Captan applications. The experimental programs included applications of labeled and experimental single-site inhibitors from several fungicide groups including the SIs, strobilurins, anilinopyrimidines (AP), and a carboxamide. The SI programs included Nova® and several experimental SI fungicides containing tebuconazole, difenoconazole, or fenbuconazole. The strobilurin programs involved applications of Flint®, while AP programs included applications of Vangard®, Scala™, or experimental mixes of these APs with SIs or strobilurins. Several fungicide programs involved an experimental carboxamide-based fungicide, and will be subsequently designated as carboxamide programs in this manuscript.

Applications of these single-site inhibitor fungicides were timed to model predicted apple scab infection periods occurring near apple phenological stages when mildew infections might occur. At the Darrow site, experimental programs targeted the infection periods from 'bloom' to '1st cover' and from 'petal fall' to '1st cover' (Table 1). By comparison, fungicide programs at the Research South site addressed application timings of: 'bloom' to '1st cover', 'petal fall' and 'pink', and prior to 'petal fall' (Table 2).

Mildew Assessment Strategy. Given recent difficulties in obtaining meaningful powdery mildew data, the choice of mildew assessment strategy was given careful consideration. Since 'primary' mildew infections (Figure 1-Top) result from buds infected during the previous summer, these symptoms were not included in the strategy as they are unlikely to have been affected by the current season's fungicide programs. Instead, assessment strategies used in the current study focused on 'secondary' infections, which consist of newly formed powdery lesions on newly-expanded terminal leaves (Figure 1-Center & Bottom). Secondary infections can occur as early as 'tight cluster' and continue throughout bloom, and are considered the target infections for powdery mildew fungicide applications. Secondary mildew infections were assessed at least ten days following the last application of a fungicide with post-infection activity using either one of two protocols described below.

The first protocol represents a consensus of compiled advice from several apple extension pathologists in the Eastern United States. This protocol consists of randomly selecting a terminal shoot with newly expanding leaves. Mildew assessment begins at the distal end of the shoot, but does not consider the youngest leaves that have not yet completely expanded (e.g. < 50% leaf expansion). From the first 'expanded' leaf, eight leaves in total moving toward the proximal end of the shoot were assessed for the presence of secondary mildew lesions (Figure 1, center & bottom). Ter-

TABLE 2

Fungicide programs implemented at the Research South farm on 'Jonagold' apples in 2007[a]

	Application Schedule				
Fungicide Program	April 30 (Green Tip – Half inch Green)	May 7 (Tight Cluster – Pink)	May 14 (Bloom)	May 18 (Petal Fall)	May 29 (1st Cover)
	Check Programs				
Untreated	No application	No application	No application	No application	No application
Protectant Program	EBDC	EBDC &/or Captan	EBDC &/or Captan	EBDC &/or Captan	EBDC &/or Captan
	Sterol Biosynthesis Inhibitor Programs				
SI: Bloom - 1C	EBDC	EBDC & Captan	SI	SI	SI
SI: before Petal Fall	EBDC	SI	SI	EBDC & Captan	EBDC & Captan
SI: +EBDC: Bloom - 1C	EBDC	EBDC & Captan	EBDC & SI	EBDC & SI	EBDC & SI
SI: +EBDC: before Petal Fall	EBDC	EBDC & SI	EBDC & SI	EBDC & Captan	EBDC & Captan
	Stroby Programs				
Stroby: Bloom - 1C	EBDC	EBDC & Captan	Stroby	Stroby	Stroby
Stroby: before Petal Fall	EBDC	Stroby	Stroby	EBDC & Captan	EBDC & Captan
	Anilinopyrimidine Programs				
AP/SI: before Petal Fall	EBDC	AP/SI	AP/SI	EBDC & Captan	EBDC & Captan
AP: before Petal Fall	EBDC	AP	AP	EBDC & Captan	EBDC & Captan
	Carboxamide Programs				
Carboxamide: at Pink and Petal Fall	EBDC	Carboxamide	EBDC & Captan	Carboxamide	EBDC & Captan
Carboxamide + Stroby: at Pink and Petal Fall	EBDC	Carboxamide & EBDC	EBDC & Captan	Carboxamide & EBDC	EBDC & Captan

[a]Fungicide abreviations are as follows: : EBDC = ethylenebisdithiocarbamate, SI = sterol biosynthesis inhibitor, Stroby = strobilurin, and AP = anilinopyrimidine

[b]'1C is First Cover

minal leaf mildew was then expressed as the number of terminal leaves with mildew out of eight terminal leaves. Ten or twenty shoots were assessed from each 'Jonagold' or 'Cortland' tree respectively.

A second protocol was designed to allow for quick mildew assessments, and to address potential difficulties in discerning discrete secondary mildew lesions. This protocol involves randomly selecting terminal leaf shoots and quickly examining the ten distal most leaves for the presence of mildew. The whole shoot is then scored as either positive or negative for the presence of mildew. Mildew raters were assigned sections for each tree and rated ten terminal shoots per section. The procedure was carried out on each single-tree treatment replication for a given treatment. This protocol was only implemented in the 'Jonagold' site this year as trees in both locations were displaying discrete mildew lesions and could be assessed with the first protocol.

Results

Powdery mildew infections developed on terminal shoots in both the 'Jonagold' and 'Cortland' orchards. In both orchard sites primary and secondary mildew infections were observed and easily discernable. The 'Cortland' planting began to show mildew symptoms the last week in June with the mean percentage of terminal leaves with secondary mildew ranging from 4.4 to 40.6% across all treatments (Figure 2). By comparison the 'Jonagold' planting began to show mildew symptoms around the second week of June with the mean percentage of terminal leaves with secondary mildew ranging from 12.8 to 56.7% and the mean percentage of shoots with powdery mildew ranging from 29.1% to 90.3% across all treatments (Figure 3). In the 'Jonagold' planting, rating infected terminal shoots per tree resulted in much higher values for powdery mildew symptoms compared to rating infected leaves on shoots. The higher values are not surprising, as the presence of a single lesion on a leaf will cause the entire shoot to be scored as having powdery mildew. There is, however, a strong relationship between the percentage of terminal leaves with mildew and the percentage of terminal shoots with mildew ($R^2 = 0.9882$, $P < 0.0001$) (Figure 4). Moreover, there appears to be a similar level of discrimination among treatments between the two methods (Figure 3). Rating terminal leaves is more widely practiced by extension scientists than rating terminal shoots. However, rating terminal shoots is accomplished much more quickly than rating terminal leaves, and could be useful in situations where labor is limited, the planting is exceptionally large, and when one wishes to rate multiple times during the season. Rating shoots may also be more appropriate when mildew lesions are indistinct due to considerable pubescence, and towards the end of the season when lesions are inactive or unchecked mildew has spread over the entire terminal.

Program timing. In the 'Cortland' planting there were no significant differences between programs with SI and strobilurin applications from 'bloom' to 'first cover' and programs with SI and strobilurin applications from 'petal fall' to 'first cover' (Figure 2). In the 'Jonagold' planting, programs with SI and strobilurin applications from 'bloom' to '1st cover' had significantly improved mildew levels compared to programs with SI and strobilurin applications that only occurred prior to 'petal fall' (Fig 3). Moreover, programs without SI and strobilurin applications at 'petal fall' and

'1st cover' were not substantially improved over the protectant and check programs. These results clearly illustrate the importance of 'petal fall' and '1st cover' applications of strobilurins and SI fungicides.

It is believed that post-infection activity should allow the SI fungicides applied at petal fall and 1st cover to suppress infections that occur at pink and bloom. The data from the 'Cortland' planting seems to confirm this hypothesis. Although the strobilurins are known to have less post-infection activity than the SIs, this year's data indicates that they were just as effective when only applied post bloom.

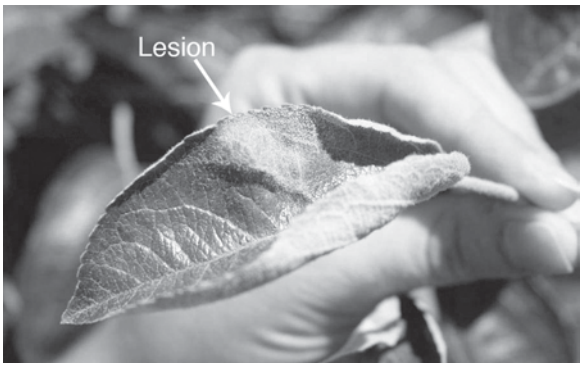

Figure 1. Powdery mildew symptoms on 'Cortland' apples. (Top) A terminal shoot completely covered with powdery mildew, which is likely to have resulted from primary (over wintering) mildew infection. (Center) Upper surface of a terminal leaf with a discrete mildew lesion likely resulting from secondary infection. (Bottom) A secondary mildew lesion on the underside of a terminal leaf.

Program performance For the most part, programs with fungicide applications within the same chemistry group (i.e. SIs) performed similarly to one another (i.e. not significantly different from one another). Because of a similar level of performance combined with the fact that several of the fungicides are still in development, only data representative of the chemistry group is presented to illustrate overall trends.

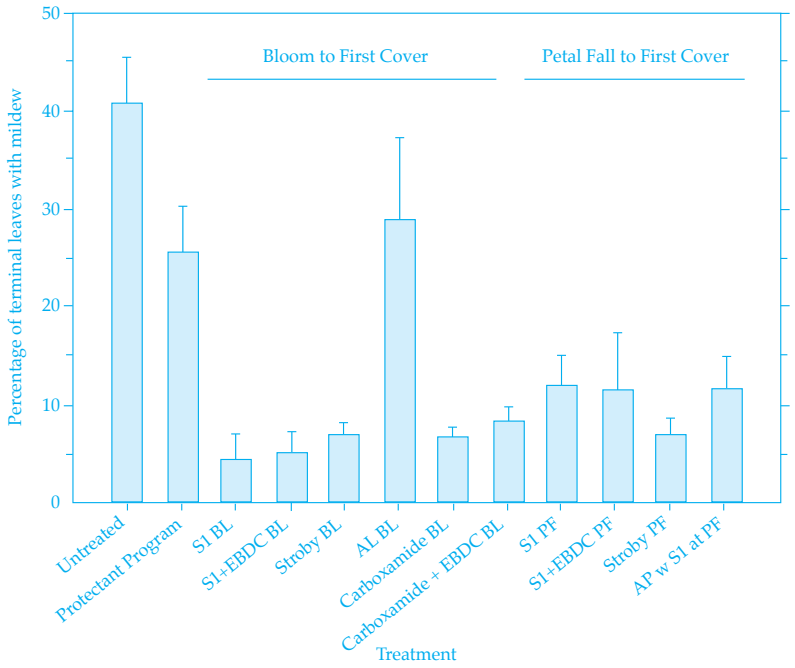

Figure 2. Percentage of terminal leaves with mildew lesions resulting from secondary infections for fungicide programs at the Darrow farm on 'Cortland' apples. Values are means and standard errors for individual terminal shoots across replicate trees for programs with mildewicide application timings from 'bloom (BL)' to 'first cover (1st)' and those with applications from 'petal fall (PF)' to 'first cover (1st)'.

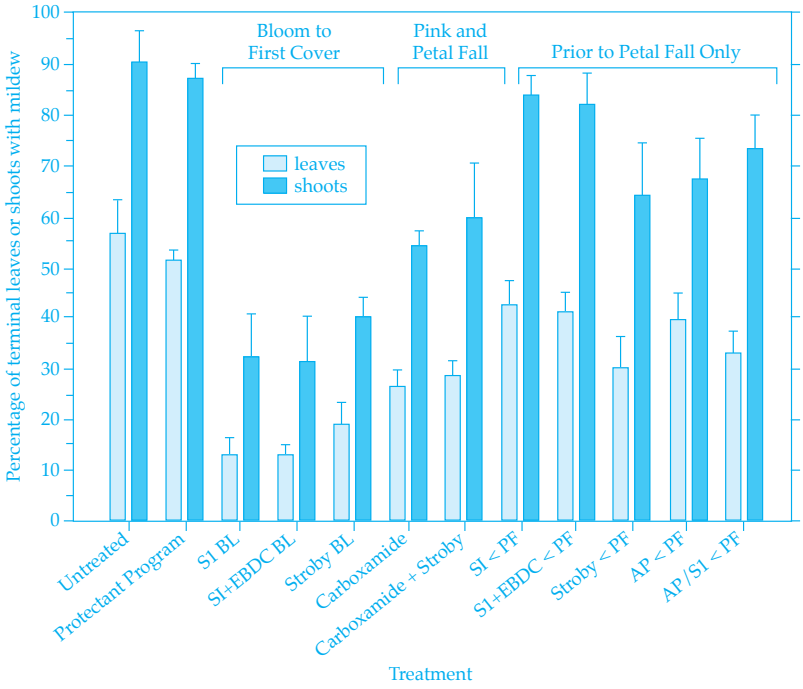

Figure 3. Percentage of terminal leaves and terminal shoots with mildew lesions resulting from secondary infections for fungicide programs at the Research South farm on 'Jonagold' apples. Values are means and standard errors of individual terminal shoots or quadrants across replicate trees for programs with mildewicide application timings from 'bloom (BL)' to 'first cover (1st)', 'pink' and 'petal fall', and prior to 'petal fall' (PF)'.

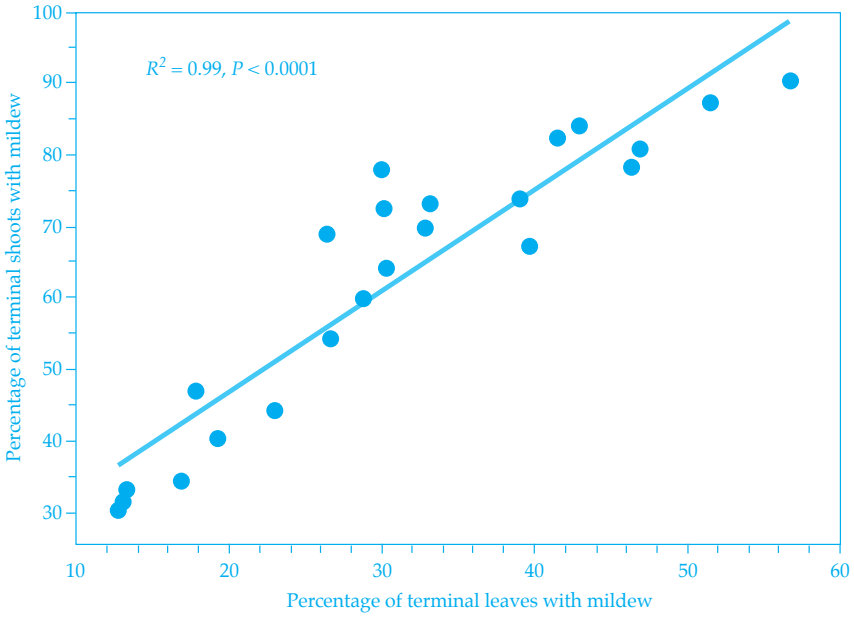

Figure 4. Linear regression of the percentage of terminal shoots with mildew on the percentage of terminal leaves with mildew (R^2 = 0.99 n = 23, P < 0.001). Values are coordinate points of treatment means across replications.

SI and strobilurin programs Across both plantings, programs with SI or strobilurin applications provided the highest level of powdery mildew control as expected (Figures 2 and 3). There were no significant differences between the performance of SI and strobilurin programs with the same application timing. The inclusion of an EBDC with SI applications afforded no additional level of control regardless of the timing. The 'Cortland' planting has an SI resistant apple scab population and for several years it was feared that the powdery mildew population might have shifted towards resistance to SI fungicides. However, data from this year's study indicate that the SIs still perform well against powdery mildew in this orchard. Considering the history of excessive SI use in the 'Cortland' planting, these results provide some indication that reports of diminished efficacy may not entirely be caused by population shifts towards fungicide resistance.

AP and Carboxamide programs The AP fungicides are known to be ineffective against powdery mildew. The data at both plantings indicate that the program with AP applications alone performed little better than the protectant or untreated programs (Figs. 2,3). In the 'Jonagold' planting, the programs with AP applications prior to 'petal fall' performed similarly to other programs of the same timing. However, all of the programs with this application timing were not greatly improved over the untreated or protectant programs. In the 'Cortland' planting, one of the AP/SI hybrid programs performed quite well (Fig 2.), but this performance is likely due to the SI applications that occurred at 'petal fall' and '1st cover'.

In contrast to the APs, the carboxamide programs were as effective as the SI and strobilurin programs in the 'Cortland' planting, but less effective than the SI and strobilurin programs in the 'Jonagold' planting (Figures 2 and 3). However, the reduced efficacy in the 'Jonagold' planting may be due to the fact that application only occurred at 'pink' and 'petal fall' as opposed to 'bloom', 'petal fall', and '1st cover', which appeared to be the most critical periods for powdery mildew this year. As one might expect, combining the carboxamide with an EBDC did not enhance mildew control at either orchard.

Although there is only one year of data, several trends were observed across the two orchard trials. Consistent with the usual periods of infection for the disease, 'bloom', 'petal fall', and '1st cover' applications appear to be most important for managing powdery mildew. Of the fungicides, the SIs, strobilurins, and the carboxamide provided the best mildew control when applied at petal fall and first cover. Performance of fungicide programs for mildew control appears to be diminished when an EBDC protectant is used at 'petal fall' or '1st cover' instead of an SI, strobilurin, or the carboxamide.

Future Research

In the previous seasons at the NYSAES, powdery mildew ratings were made closer to harvest. However, in recent years late season mildew data hasn't been very meaningful as the symptoms became too difficult to discern at the time of harvest. Because of the recent difficulties with late season mildew assessment, an effort was made to rate mildew earlier in the season. However, one must speculate as to whether unchecked mildew continues to lead to subsequent infections throughout the summer. Indeed, the 'Jonagold' planting still appears to have active lesions, and in the fall of 2006 numerous mildewed leaves and severely russetted apples were observed on some treatments.

Unfortunately, discrete lesions have become nearly impossible to discern as August approaches, but mildewed terminal shoots are readily apparent. Given that a good relationship exists between terminal leaf mildew and terminal shoot mildew, late season shoot assessments will be made in the 'Jonagold' planting to see whether mildew has increased over the summer. Since the summer program consists entirely of Captan applications, which have no mildew activity, potential late season mildew infections would go unchecked. Should levels have dramatically increased, investigation into the impacts of the summer disease program on late season mildew in susceptible cultivars will be pursued the following year.

References

Rosenberger, D. A. 2007. Controlling powdery mildew on apples. *Scaffolds* 16(8): 6-8.

Yoder, K.S., Hickey, K.D., and Biggs, A.R. Powdery Mildew, Podosphaera leucotricha. http://www.caf.wvu.edu/Kearneysville/disease_descriptions/ompowmil.html. West Virginia University, Kearneysville Tree Fruit Research and Education Center

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