Spinach Downy Mildew

Threat, Prevention and Control

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Introduction – disease symptoms and the spinach downy mildew pathogen

Downy mildew diseases of crops can be very difficult to control, especially when synthetic chemical fungicides are not available, or their usage is not allowed, as in organic production. As in the case with most other crops damaged by downy mildews, spinach downy mildew disease culminates in the field with yellow spots on the leaves (chlorosis) as shown in Figure 1A. Examination of the underside of the diseased spinach leaf reveals gray downy masses (Fig. 1B) of microscopic spores (also known as sporangia, plural) that are borne on structures known as sporangiophores (Fig. 2A). Sometimes the fuzzy mat of sporangia and sporangiophores appears purplish and can also form on the top leaf surface, though less commonly. Microscopic sporangia can readily become airborne, and there may be thousands of these spores per leaf, each capable of causing another downy mildew infection on a nearby, or downwind, spinach plant.

Spinach downy mildew disease is caused by the pathogen *Peronospora effusa*, a scientific name abbreviated simply as *P. effusa*. The scientific name of the organism for the causal agent of spinach downy mildew has undergone changes over the last 150 years, and therefore, when scanning the literature on the topic of spinach downy mildew, these changes are important to keep in mind. For a period of about 50 years, until very recently, the pathogen was most commonly referred to in the scientific literature as *Peronospora farinosa* f. sp. *spinaciae*. The "f. sp." refers to a form species of *P. farinosa*, that infects spinach, "spinaciae". However, the available morphological and genetic data indicate that like other *Peronospora* species, *P. effusa* is distinct, requiring a name change to the original scientific name of *Peronospora effusa*.

Photo Credit: Steven J. Klosterman

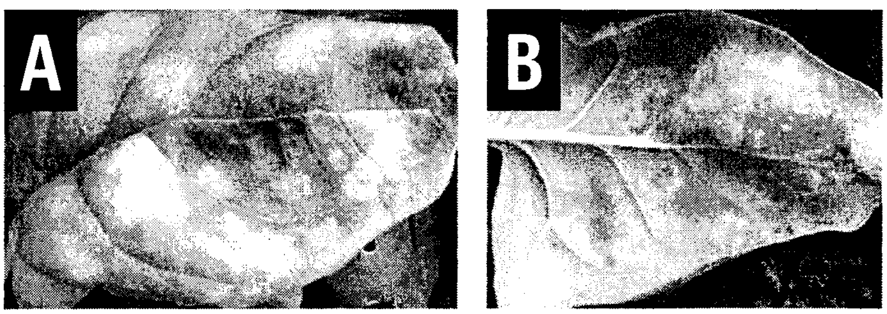

Figure 1. Typical symptoms and signs of downy mildew on spinach. A) Top of an infected leaf revealing chlorotic spots; B) The underside of the same leaf exhibiting gray-brownish masses of sporulation from the downy mildew pathogen.

Photo Credit: Steven J. Klosterman

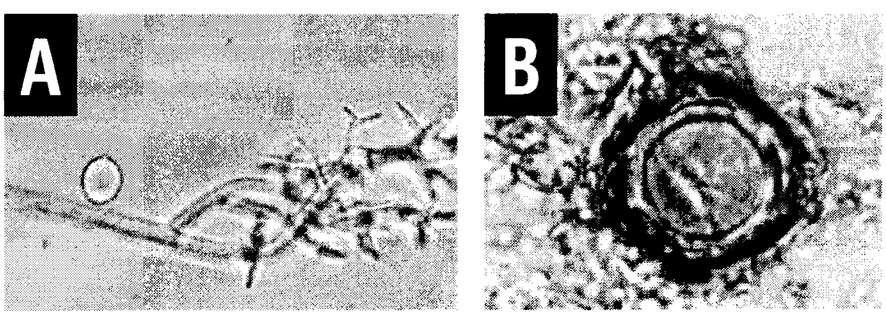

Figure 2. Asexual and sexual spores formed by Peronospora effusa, the cause of downy mildew on spinach. A) A single oval-shaped sporangium and the typical branching pattern of the sporangiophore on which the sporangia are borne; B) An oospore of the spinach downy mildew pathogen derived from a commercial spinach lot in 2014. The asexual sporangium and sexual oospore are microscopic, and each type is approximately 30 micrometers in diameter.

Peronospora effusa belongs to a group of organisms known collectively as the oomycetes, which derive their name from the sexual structures, or the oospores, that they form. Oospores enable the oomycetes to survive 2-3 or more years, and therefore to potentially be transported long distances on seed and even survive long periods in the soil. The microscopic oospores of *P. effusa* have a very distinctive smooth, round wall (Fig. 2B) lacking spikes or other ornamentation found on the walls of the oospores of some oomycete species. For mating and the production of oospores to occur, available evidence indicates a requirement of two different mating types, borne on separate thalli (or bodies of two separate strains).

Peronospora effusa also has a very limited or narrow host range. Unlike some other related pathogens, or even many fungal pathogens, there is no evidence that *P. effusa* infects other crops and weedy plants found near spinach production areas. Rather, a series of pathogen cross-inocu-

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lation tests dating back to the 1930s have repeatedly shown that *P. effusa* only infects spinach, and not related plants, even those within the same plant family (Amaranthaceae).

Like other downy mildews, *P. effusa* infection requires some leaf wetness, and the disease is also favored under cooler conditions. Widespread use of overhead irrigation and dense spinach plantings in California and Arizona, where approximately 90 % of the U.S. fresh market spinach is produced, ensure that moisture levels are conducive for the disease.

Spinach Downy Mildew -- threat to organic spinach production

There has been a dramatic increase in the amount of organic spinach produced over the last two decades in the U.S. Today, some estimates indicate as much as 30 % of all fresh market spinach is produced for the organic market. In the last ten years there has been mounting concern that the pathogen will be unstoppable due to a lack of durable resistance, especially for organic spinach production, where fungicides are not available to effectively control downy mildew. In fact, at an industry-sponsored meeting held in Seaside, California, in mid-2014, the alarm was evident, with some growers suggesting that organic production of spinach may cease within ten years in the U.S., due to losses caused by downy mildew. Thus, there is especially a need to establish downy mildew disease control measures or management methods that can be adopted for organic spinach.

Deploying spinach cultivars that are bred to resist downy mildew has been deemed the most effective strategy for managing this disease, at least for organically grown spinach. Just as plant breeders are able to breed spinach plants through natural genetic crosses, and select for particular traits, such as disease resistance, the pathogen populations also change and adapt very quickly to overcome this resistance. One of the reasons for the quick adaptation of the pathogen is the short lifecycle, which produces thousands of offspring from a single leaf. In situations where a single gene for resistance is naturally bred into spinach, the pathogen has rapidly adapted and overcome this type of resistance. Genetic variants, or different genotypes of the pathogen, with new pathogenic capabilities, may also arrive in a new area as oospores, like the one shown in Figure 2B. If these oospore populations contain new pathogenic traits, this could contribute to the breakdown of resistance. Durable (long-lasting) disease resistance is most desired, but takes additional effort over a longer period to breed for this type of resistance, which does not rely on one or two major genes. Inevitably this type of resistance will help to control downy mildew for conventional production as well, and even more cost-effectively with reductions in the use of fungicides.

While plant disease resistance has been the most important tool in the fight against downy mildew on spinach, spinach cultivars with resistance to all of the different pathogenic variants *P. effusa* have become increasingly scarce. In fact, no cultivar is currently resistant against all of the pathogenic variants. The spinach downy mildew pathogen populations in California and Arizona have demonstrated the remarkable ability to continuously overcome the genetic resistance to downy mildew that is bred into the spinach cultivars. Hence, the threat to organic spinach production remains very real.

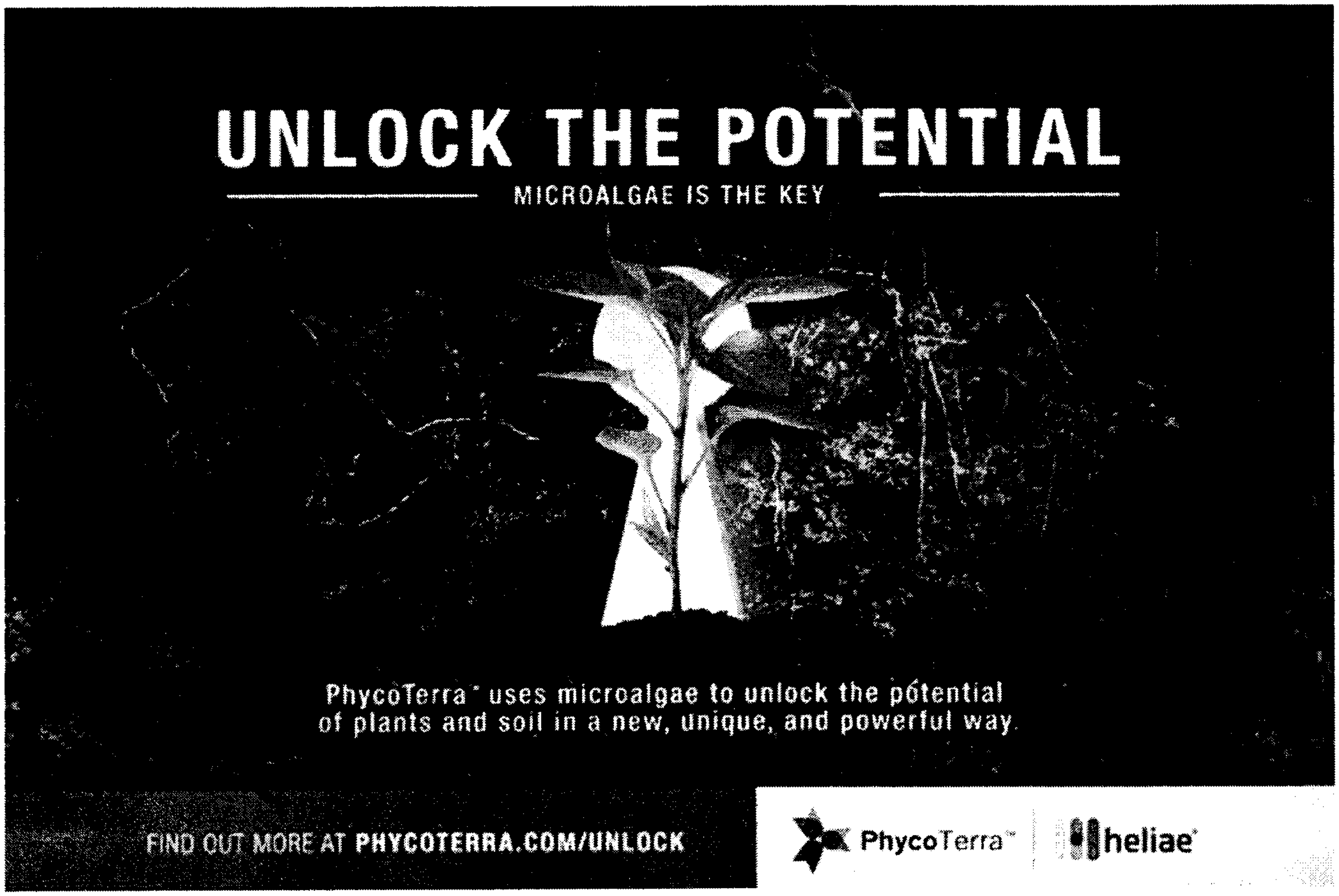
Short term solutions and preventative measures

The United States Department of Agriculture, Agricultural Research Service (USDA ARS) in Salinas, California is currently leading collaborative efforts with University of California researchers to prevent pathogen introduction into cropping systems and to provide tools for growers and pest control advisors (PCAs) to diagnose the pathogen in the field early, before symptom development, to reduce or eliminate economic losses caused by spinach downy mildew. Aspects of this research are currently funded by both the California Leafy Greens Research Program and the California Department of Food and Agriculture Specialty Crop Block Grant Program.

Oospores, like the one shown in Figure 2B were recently identified in 13/82 (16%) of modern seed lots examined. This is disconcerting since oospores of this pathogen are predicted to survive 2-3 years in soil or on seed, based on what is known about similar organisms that produce oospores. The oospores can germinate and cause disease, as determined by a study conducted in Japan in the 1980s, and published in the journal Phytopathology. It is also the most likely explanation for the disease appearing on spinach fields "in the middle of nowhere" as one grower described it. Thus, the elimination or reduction of oospores arriving on spinach seed destined for organic production should be considered in protecting spinach crops against downy mildew.

In addition, early detection of *Peronospora effusa* using DNA-based techniques can be applied to determine whether leaves in a field are infected with the pathogen, but not yet showing symptoms. This can be a powerful advantage for the spinach industry. For organic production of spinach, such early detection tools can be valuable to cut losses and harvest the crop early. In many instances, there is still a chance to salvage the crop early, rather than having a devastating disease outbreak destroy the entire field.

For conventional spinach production, where synthetic fungicides can be applied for effective disease control, the new technology allowing early diagnosis in the field will enable the grower to determine whether to spray, thereby saving the rest of the crop from destruction. Reducing overall fungicide usage also helps to reduce fungicide resistance in the pathogen populations. Steve Koike (University of California Cooperative Extension, Monterey County) indicated that there are currently many effective fungicides available for preventative control of spinach downy mildew, if used properly. Some of these commonly



used products include Revus, Reason, Ranman, Presidio, and Aliette. Another commonly applied fungicide for control of spinach downy mildew is Ridomil, which is applied at planting but not as a foliar application. So while there are many effective products to choose from, there are a multitude of other considerations about which fungicide to use, such as price and availability. An additional consideration is P.H.I, or preharvest interval, since the field can be harvested more quickly with the use of certain fungicides with a shorter P.H.I.

Currently, downy mildew disease forecasts and available models can be helpful, but even greater precision is required to guide those important decisions on the best timing for spray applications to maintain crop health. The research on this early detection approach in the field, in spinach leaves, involves replicate field studies, and should be completed within the next two years.

Research also conducted by the USDA ARS in Salinas, in collaboration with the University of California, involves spore trapping, to detect airborne sporangia, like the oval-shaped one shown in Figure 2A. These efforts have led to a greater understanding of inoculum sources in the Salinas Valley of California, where a large portion of the U.S. fresh market spinach is produced between April and November. By monitoring the airborne spore traps using DNA-based techniques, the research revealed that a low level of the airborne pathogen is typical, as the pathogen DNA has been routinely detected, even in the winter months of December through March, when very little if any spinach is grown in the Valley. This makes timing spray applications based upon simple presence or absence of the pathogen impossible. However, the DNA assays from the spore trap samples are also quantitative. In other words, we know roughly how many spores are present (inoculum load) at a given time based upon the amount of DNA of the pathogen present. Thus, there is currently an ongoing effort by USDA and University of California researchers to decipher how increases in local pathogen inoculum load in small areas of the Salinas Valley are impacted by various weather parameters for the purposes of disease forecasting. PCC

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