EXPECT AND PREPARE FOR DOWNY MILDEW IN BASIL

Margaret Tuttle McGrath
Department of Plant Pathology and Plant-Microbe Biology, Cornell University
Long Island Horticultural Research and Extension Center
3059 Sound Avenue, Riverhead, NY 11901; mtm3@cornell.edu
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Downy mildew of basil is a new, destructive disease that appears to be here to stay. It was first reported in south FL in October 2007. In 2008 downy mildew was confirmed in both field- and greenhouse-grown basil crops, as well as home gardens, in many states: NC, PA, NJ, NY, MA, NC, KS, and MO. Likely it occurred elsewhere but was not recognized. Growers generally did not realize their basil had a disease because the most noticeable symptom on affected plants was yellowing resembling a nutritional deficiency. The downy-appearing sporulation of the pathogen develops on lower leaf surfaces. And, since downy mildew of basil is so new in the USA, few knew about it. Complete crop loss occurred for some growers because leaves with any injury are unmarketable. This disease was also reported in Canada in 2008 and in greenhouse-grown basil in Argentina in February 2008. In 2009 basil downy mildew was found in the western USA, and early in 2011 it was reported in Hawaii for the first time. Downy mildew has been observed on basil in several states every year since 2008.

Reports of downy mildew began a few years earlier in Europe, where the disease is now considered endemic. It was observed in greenhouses in Switzerland in 2001, Italy in 2003, and Belgium plus France in 2004. Basil downy mildew has also been detected recently for the first time in Israel, New Zealand, Iran and several African countries: Cameroon in 2007, South Africa in 2005, plus Benin and Tanzania.

So where did this new scourge come from? Prior to all these recent outbreaks, basil downy mildew had only been reported in Uganda and that was in 1933. One possibility is that a more aggressive pathogen strain evolved in Uganda that is responsible for the recent outbreaks. The pathogen (*Peronospora belbahrii*) can be seed-borne, as well as dispersed via its air-borne spores. Unknowingly distributing contaminated seed is a plausible way that it has been spread long distances between geographically-separated areas, including in to the USA. Basil growers may recall with frustration a similar situation years ago with another new disease: Fusarium wilt. In just a few years, as the cause of this wilt was being identified, the pathogen became endemic most likely as the result of marketing of contaminated seed. It also is possible that spread of the basil downy mildew pathogen occurred through marketing of infected, basil leaves that were asymptomatic during shipment. Basil in the US has become the leading culinary herb and is available year round. An estimated 20% of the total basil sold is imported from other countries. The pathogen found in FL has been shown to be genetically the same as that in Switzerland (100% homology in their genetic sequences). Once downy mildew has begun to develop in one crop, the pathogen can readily spread via the easily wind-dispersed spores that it produces abundantly. This is likely the main way it has spread throughout the eastern USA every summer since 2008, similar to its well-known relative, the cucurbit downy mildew fungus.

A monitoring program was started in 2009 to obtain information on where basil downy mildew occurs and to try to determine whether the pathogen could move northward through the eastern USA, now that it is considered established in FL, as occurs with the cucurbit downy mildew pathogen, and whether a monitoring program can assist growers to be prepared for downy mildew occurrence in their basil crop. Each year a spreadsheet accessible by anyone has been set-up in Google Docs. These pages are at:

For 2018: https://docs.google.com/spreadsheets/d/1lHTfaVYxjjr7CxbEJiv8qgYmB5VdMFdT_4ehfjQrc5U/edit#gid=0
For 2017: https://docs.google.com/spreadsheets/d/1RWK_C-VoNOtjzNfd4TNn-b7KBFdoF-czmSJ193ve7Cc/edit#gid=0
For 2016: https://docs.google.com/spreadsheets/d/1cLrXIQfPjPa0z1Bw6LRYdvjYhz7-5HXkmfCQMnJrvko/edit#gid=0
For 2015: https://docs.google.com/spreadsheets/d/1JgKGmCP-0I2A03J0BG2EafNctvQTiaUUnbqJbYfQhVk/edit#gid=0
For 2014: https://docs.google.com/spreadsheet/ccc?key=0Ak8NCmWCdGPNdGFIUVZuT1ZhVmR1VDBPcUR5WkFtSkE#gid=0
For 2013: https://docs.google.com/spreadsheet/ccc?key=0Ak8NCmWCdGPNdFR6bFBxRERJQjdaYXd5VlZJYWNNX2c#gid=0
For 2012: https://docs.google.com/spreadsheet/ccc?key=0Ak8NCmWCdGPNdEZxSUdxYTNKaUJueU8tTG1Jd2tmTFE#gid=0
For 2011: https://spreadsheets.google.com/ccc?key=tphmBim45_9rRh31XfV7OeA&hl=en#
For 2010: http://spreadsheets.google.com/ccc?key=tpjIzTOV96rlFTVvvYXIa3w&hl=en
For 2009: http://spreadsheets.google.com/ccc?key=pwvp1mHxmowsEd8Sdi4coNQ

A total of 1197 reports of basil downy mildew were logged from 44 states plus the District of Columbia from 2009 to 2017. More reports of downy mildew in 2014 than previous years was associated with affected plants for sale at garden centers in several states and cooler temperatures in the North Carolina to Maryland area where typical high summer temperatures might have limited downy mildew development in other years. 31 reports were from 18 locations outside the USA. Most reports were made by home gardeners, growers and extension specialists of sightings on outdoor plants. Affected plants were also seen in greenhouses. Many reports were confirmed by sending photographs to M. T. McGrath or because they came from reporters with expertise to identify downy mildew; some were not confirmed. More information and occurrence maps are at http://blogs.cornell.edu/livegpath/extension/basil-downy-mildew/where-in-the-usa-is-basil-downy-mildew/

Many more occurrences have been acknowledged but not logged. Another monitoring activity has been sentinel plots with basil conducted as an add-on to the *ipm*PIPE cucurbit downy mildew monitoring program. In 2009, downy mildew was observed in sentinel plots in seven of the 14 states with these plots. There were other reports of downy mildew in these states logged in the web-based monitoring spreadsheet. There were two states with no reports of downy mildew in plots or elsewhere. Thus occurrence of downy mildew in the sentinel plots in a state often reflected disease occurrence in that state.

Success of the monitoring program depends on reports from anyone growing basil; therefore everyone is encouraged to enter observations. Information is needed about the planting and how the diagnosis was made. Reports are also valuable of locations where downy mildew is not found on basil. Monitoring will assist with determining whether seed is becoming a less important source, as expected with the pathogen's ability to be seed-borne becoming well known, and whether movement of the pathogen via its wind-dispersed spores can be predicted based on knowledge of where downy mildew is occurring and forecasts of wind trajectories plus weather, as is done now for cucurbit downy mildew. Even before a forecasting system like that for cucurbit downy mildew can be developed, growers and gardeners alike will be able to look at reports in the spreadsheet to see if basil downy mildew has been observed nearby.

Downy mildew also was observed recently on ornamental plants related to basil, in particular coleus and salvia. These plants all belong to the Lamiaceae family, which includes basils (*Ocimum* spp.), mints (*Menta* spp.), sages (*Salvia* spp.) and other culinary herbs. Fortunately, the coleus and basil downy mildew pathogens have now been demonstrated to be genetically different; therefore, these ornamental plants are no longer considered potential alternative hosts. However, there are many ornamental types of basils that are also hosts to the pathogen affecting basil grown for use as an herb.

The first step in preparing for basil downy mildew is learning the symptoms. Observing spores on the underside of leaves is key to diagnosis. There are other causes of leaf yellowing in basil. Spores are produced during the dark night period, therefore early morning is the best time to inspect basil for downy mildew. Leaves with yellowing resembling downy mildew but lacking spores can be placed upside down on wet paper towel in a closed plastic bag in dark for a day to encourage the pathogen if present to produce spores. Photographs are posted at: http://blogs.cornell.edu/livegpath/gallery/basil/downy-mildew/
Next become familiar with the monitoring web page to be ready to use it after planting. Finally, develop a management plan.

Management. Using seed not infested with the basil downy mildew pathogen, selecting a less susceptible variety, and applying fungicides are the primary management practices for downy mildew. Pathogen-free seed is most important for plantings not expected to be exposed to wind-dispersed spores, such as greenhouse crops when too cold outdoors for basil to survive. Minimizing leaf wetness and reducing humidity to obtain conditions unfavorable for disease development may suppress downy mildew, especially in greenhouses. An article focused on management in greenhouses is available as a PDF

Seed Tests. Recent efforts to develop a seed test have resulted in a genetic-based procedure specifically for *Peronospora belbahrii* that is now being validated (suspected contaminated seeds are needed for this step, see information about submitting samples below). And Eurofins STA Laboratories in CO (http://www.eurofinsus.com/stalabs/products-services-seed-health.html) now tests basil seed for *Peronospora* spp. It is sufficient to test only at the genus level with this pathogen since it is the only species of *Peronospora* that would be associated with basil seed.

Seed Treatment. Seed companies (including High Mowing Organic Seeds) are starting to steam treat basil seed. It is not amenable to hot-water treatment because while in water the seed produces a gelatinous exudate.

Varieties. Good suppression of downy mildew can be obtained with new resistant varieties that started to be marketed in 2018. They are the fruition of several years of conventional breeding by breeders working separately on this goal. It can take many crosses to obtain a plant with resistance plus all the desired horticultural traits that are in a susceptible variety, which include for sweet basil large, smooth, dark green, downward cupped leaves with good classic sweet basil flavor.

Devotion, Obsession, Passion, and Thunderstruck are the first resistant varieties released from the Rutgers University basil breeding program. They are marketed by VanDrunen Specialty

Seeds. Organically-produced seed is available. Results from evaluating these varieties at Cornell are available on-line along with evaluations conducted earlier that documented high level of resistance of Rutgers experimental crosses during the development of the resistant varieties. Some symptoms did develop on the resistant varieties which is typical because disease resistance is rarely immunity.

Prospera is being marketed as organic seed by Johnny's Selected Seeds. No symptoms were found on plants in the evaluation conducted at Cornell in 2018. In some evaluations conducted elsewhere there were some plants that became affected which could be due to seed mix up.

Amazel is a Proven Winners variety that also did not develop symptoms in the Cornell 2018 variety evaluation. Its seed is sterile and thus sold as cuttings primarily for producing plants for the home garden market.

Limited suppression is typical with Eleonora, the first commercially available resistant variety. Emma and Everleaf (aka Basil Pesto Party and M4828Z when evaluated at Cornell) also have moderate resistance.

Grower feedback on performance of downy mildew resistant varieties in terms of disease suppression, yield, flavor, appearance, marketability, etc. would be greatly appreciated.

Research on resistance started with looking to see if there are inherent differences in susceptibility among varieties and species of basil, and to identify sources of genetic resistance. Commonly grown sweet basil (*Ocimum basilicum*) was shown to be more susceptible than some of the other exotic, spice, and ornamental basils such as *Ocimum citriodorum* and *Ocimum americanum*. All sweet basil varieties evaluated before breeding for resistance was started were found to be very susceptible. Other basil varieties with fewer symptoms in evaluations include red types (including 'Red Leaf' and 'Red Rubin'), Thai basil (Queenette'), lemon basil ('Lemon', 'Lemon Mrs. Burns', 'Sweet Dani Lemon Basil'), lime basil ('Lime'), and spice types ('Spice', 'Blue Spice', 'Blue Spice Fil', 'Cinnamon'). An article on this study is available as a PDF. Similar results were obtained in trials conducted in Illinois and Florida. Fewer symptoms were observed only on those basils that are different from sweet basil being distinct in visual appearance, aroma and flavor, and which have quite limited markets. The challenge in breeding for resistance to basil downy mildew is to develop improved resistant varieties that still look, taste, grow and pack-out as a traditional high quality sweet basil.

To achieve acceptable control, all resistant varieties need to be used with other management practices, in particular fungicides, due to very low tolerance for symptoms in herbs especially when used fresh.

Fungicides. To control downy mildew effectively with fungicides, it is considered necessary to start before first symptoms and to make applications frequently. Many of the fungicides currently labeled for this new disease, plus others not registered yet, have provided limited suppression in some fungicide evaluations, demonstrating the difficulty in controlling this disease, especially in a research setting with applications made with a backpack sprayer, and thus

the importance of starting before disease onset. Part of the challenge of controlling downy mildew is the need for blemish-free herbs when marketed as fresh sprigs.

To determine when to initiate a fungicide program and also when it is warranted to consider harvesting early to avoid losses to downy mildew, growers should not only routinely check the on-line spreadsheet to determine when downy mildew is occurring on basil nearby, but also regularly inspect their crop for symptoms. The cucurbit downy mildew forecasting web site (http://cdm.ipmpipe.org) might be useful for predicting when conditions are favorable for basil downy mildew since both pathogens likely have similar requirements for successful wind dispersal long distances (e.g. overcast skies) and subsequent infection (e.g. wet leaves or high humidity). Summer is not a time to forget about this disease: unlike most other downy mildew pathogens, e.g. the ones affecting lettuce and cruciferous crops, which stop developing in summer, the basil downy mildew pathogen seems to develop best under moderate to warm temperatures while also tolerating cool temperatures. Don't forget to report occurrence of downy mildew as soon as possible at the monitoring page or via e-mail to mtm3@cornell.edu.

Organic Fungicides. Basil has been added to the list of herbs on the label for Cueva (10% copper octanoate). Downy mildew is in the list of foliar diseases controlled by this OMRI-listed product. Procidic (3.5% citric acid) is specifically labeled for basil downy mildew. It is exempt from EPA registration under FIFRA and thus does not need to be registered in NY. It was reviewed and determined to be NOP compliant by Washington State Dept of Ag. Actinovate AG (active ingredient is *Streptomyces lydicus*), Double Nickel 55 (*Bacillus amyloliquefaciens*), MilStop (potassium bicarbonate), Regalia (extract of *Reynoutria sachalinensis*), Trilogy (neem oil), and OxiDate (hydrogen dioxide) are OMRI-listed fungicides labeled for use on herbs and for suppressing foliar diseases including downy mildew. MilStop, Regalia, and OxiDate are labeled for use outdoors and in greenhouses. The Actinovate, Cueva, Double Nickel, Procidic, and Trilogy labels do not have a statement prohibiting use in greenhouses. Double Nickel label has directions for greenhouse use for soil-borne pathogens. OxiDate has limited residual activity and thus if used should be combined with or followed by another product. Results from research evaluating most of these products conducted at Cornell, which document challenge of controlling downy mildew organically, are available on-line.

Conventional Fungicides for Field-Grown Basil. Ranman (cyazofamid; FRAC code 21), Revus (mandipropamid; FRAC 40), Quadris (azoxystrobin; FRAC 11), Armicarb (potassium bicarbonate), and phosphorous acid fungicides (FRAC 33) can be used in conventional production of basil, in addition to the fungicides listed above. Quadris is the only one of these that is not permitted to be used in a greenhouse. It can be applied 6-15 times depending on rate with no more than 2 consecutive applications. Ranman is the first product labeled with targeted activity for oomycetes, the group of pathogens that includes those causing downy mildews. Ranman can be applied 9 times with no more than 3 consecutive applications which must be followed by the same number of applications of other fungicides. Revus can be applied 4 times with no more than 2 consecutive applications. There are several phosphorous acid (phosphanate) fungicides labeled for this disease with no use restrictions, including ProPhyt, Fosphite, Fungi-Phite, Rampart, pHorsepHite, and K-Phite. Quadris is labeled for use on basil but not specifically for downy mildew; it also has been shown to be effective for this downy mildew. In states like NY where the target disease is required to be specified on the label, Quadris cannot be used

without an approved FIFRA 2(ee) recommendation, which the applicator must possess when using (the one for NY can be downloaded from the NY pesticide database). These fungicides with targeted activity are prone to resistance development due to their single site mode of action and thus need to be used within a fungicide resistance management program. Resistance to mefenoxam (Ridomil) developed quickly in Israel demonstrating the capacity of this pathogen to develop resistance. Ranman and Revus are the first fungicides registered as a result of assistance from the IR-4 program. Results from research conducted at Cornell documenting efficacy are available on-line.

Conventional Fungicides for Greenhouse Basil. Ranman, Revus and phosphorous acid fungicides are permitted to be used in a greenhouse. See previous paragraph for use information and resistance concerns. Heritage (azoxystrobin; FRAC 11), Micora (mandipropamid; FRAC 40), Segovis (FRAC U15), and Subdue MAXX (mefenoxam; FRAC 4) are additional fungicides that can be used in greenhouse-grown plants for retail sale to consumers. Subdue MAXX and Segovis use are on supplemental labels available in the CDMS database and the NYS Pesticide database. Applicators must have these. Subdue can be applied once to plug-production trays after seeding and before seedling emergence and once after plugs are transplanted to larger pots. It must be tank-mixed with another fungicide labeled for this use. Heritage can similarly be applied only once at each production stage but both applications are to foliage. It must be applied in alternation with another fungicide. Micora and Segovis can only be applied to foliage of plants for retail sale as transplants; they are not permitted used on plants to be marketed as fresh herbs in grocery stores. Both can be applied at most twice to a crop. Micora can only be used in an enclosed greenhouse with permanent floor. Segovis can also be used in outdoor nurseries. It is important to use a fungicide resistance management program including alternation among as many chemistries based on FRAC code as possible.

Please Note: The specific directions on fungicide labels must be adhered to -- they supersede these recommendations, if there is a conflict. Any reference to commercial products, trade or brand names is for information only; no endorsement is intended.

Other Practices. Practices that minimize leaf wetness and reduce humidity may contribute to control. These include planting where there is full sunlight and good air movement with rows parallel to the prevailing wind direction, maximizing plant spacing, and using drip irrigation. However, these practices will not suppress dew formation or high humidity overnight creating very favorable conditions for infection and spore formation. Gardeners can avoid by bringing potted plants indoors. Humidity can be lowered in greenhouses by using circulating fans and lights, by increasing temperature, and with dehumidification. Humidity needs to be below 85% within the plant canopy to suppress downy mildew. Observations of downy mildew occurrence in field and greenhouse basil plantings suggest that environmental conditions can significantly affect severity of downy mildew.

Fanning is a practice developed and being used in Israel for basil grown in protected culture. It entails directing greenhouse fans toward plants so that leaves move. This prevents water depositing on leaves when humidity is high.

Illuminating either leaf surface of plants growing under protected conditions during nighttime was shown to effectively suppress downy mildew by inhibiting spore production through a study conducted in Israel. Light was supplied in high tunnel-like structures with 20W Day Light fluorescent bulbs each equipped with a white metal reflector (30 cm diameter), with one bulb per meter row. Spores formed on leaf tissue shaded by other leaves, thus this procedure is most effective when plants are small. Initial experiments were done with illumination throughout night. Recent research has revealed light exposure is most important during the first 6 hours of night. Red light was shown to be the most inhibitory under laboratory conditions. Downy mildew also developed slower on basil under red light in a greenhouse experiment conducted in Florida. http://www.sciencedaily.com/releases/2015/07/150722092238.htm

High temperature is lethal to the pathogen. Maximum temperatures for infection, colonization, and spore production are 80 – 88 F. Research conducted in growth chambers demonstrated that temperatures up to 113 F kill spores and mycelium of the pathogen in affected plants, with length of effective exposure decreasing with higher temperature range, least being 6 - 9 hours at 104 – 113 F. Subsequently solar heating has been used to cure plants in Israel by closing greenhouse vents or using a transparent IR polyethylene sheet covering during sunny days. It is recommended done at first sign of downy mildew and over 3 consecutive days with 3 – 4 hours exposure. It necessitates routine monitoring to ensure temperature reaches effective range while not rising high enough to kill plants. If temperature does not go about 95 F, treating for a fourth day is recommended.

Basil crops should be disked under or otherwise destroyed as soon as possible after last harvest, or when abandoned because of disease, to eliminate this source of inoculum for other plantings. A sunny day is the best time to physically destroy an affected crop because the disturbed spores will be killed by UV radiation.

Basil Downy Mildew Monitoring Program

With basil downy mildew now established in Florida, a monitoring program has been on-going since 2009 to determine whether this pathogen can move northward through the eastern USA as occurs with the cucurbit downy mildew pathogen, and whether a monitoring program can assist growers and gardeners to be prepared for downy mildew occurrence in their basil. The success of this activity depends on reports from anyone growing basil. Reports are also appreciated from outside the USA.
To report your observations and see those of others, go to:
https://docs.google.com/spreadsheets/d/1lHTfaVYxjjr7CxbEJiv8qgYmB5VdMFdT_4ehfjQrc5U/edit?usp=sharing

Please enter your observations in a line at the bottom of the spreadsheet and send an e-mail to mtm3@cornell.edu. Some column headings have instructions that will appear when the cursor is put over the heading. Include information about the planting and how the diagnosis was made. If you are unable to confirm the diagnosis microscopically, please contact your local diagnosis service for assistance or send an e-mail with close-up image of symptoms to mtm3@cornell.edu. Consult this site during the growing season to determine where downy mildew is developing in the USA. Data can be sorted by any column by clicking on the letter designation for a column and then selecting Sort under Tool. Re-sort by date when you are done.

Recent Publication: Basil downy mildew (*Peronospora belbahrii*): Discoveries and challenges relative to its control in July 2015 Phytopathology.