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Late Blight of Tomato (*Phytophthora infestans*)

Scot C. Nelson

Department of Plant and Environmental Protection Sciences

The tomato (*Lycopersicon esculentum* L.) is one of the most widely grown vegetable food crops in the world, second only to the potato. Crops of tomatoes have socioeconomic importance to families, gardeners, farmers, laborers, marketers, retailers, chefs and other workers and services in the food and restaurant industries in Hawai'i.

Tomatoes rank as the 10th most valuable agricultural commodity in the state, with a 2005 production value of more than \$9.7 million. In addition, there are numerous unaccounted backyard or small tomato gardens in the state, making the tomato plant one of the most important and widely grown food crops.

Yet, a humid and tropical environment favors certain plant diseases. The fact that one lives in the subtropics where the climate allows year-round cultivation of tomatoes does not mean it is necessarily a good idea to do so, as many unsuspecting gardeners have learned. A destructive disease, late blight caused by *Phytophthora infestans*, awaits the tomato where it is cultivated in moist, cool, rainy, and humid environments.

This plant pathogen is one of the most notorious and devastating organisms in recent human history, being responsible for the terrible Irish potato (*Solanum tuberosum*) famine in the 1840s, and it is arguably the most important pathogen of potatoes and tomatoes worldwide.

If you planted tomatoes in November and December of 2007 in or near Hilo, Waimea, Kurtistown, Mt. View, Glenwood, Volcano, or Oceanview on Hawai'i, or any other areas in Hawai'i where cool, rainy, and humid conditions prevailed, you may be wondering what happened to your crop. Perhaps you left for a weekend visit to O'ahu and returned after a few days to find your plants virtually destroyed.

This publication describes late blight of tomato and discusses ways to deal with this potentially devastating plant disease.

Host

The tomato is a perennial plant in the Solanaceae, the nightshade family, with weak, woody, densely hairy stem that often vines over other plants. It reaches 3–10 ft in height (1–3 m) and bears clusters of edible fruits classified as vegetables.

Native to Central, South, and southern North America (Mexico to Peru), tomato is now grown in most arable locations of the world, either as an indoor or outdoor crop, hydroponically or in soil.

Pathogen

Phytophthora infestans (Mont.) de Bary is not a true fungus, but rather is regarded as a fungus-like organism. This pathogen is currently classified as an Oomycete, which are members of the kingdom Chromista (Stramenopiles or Straminopiles). Oomycetes belong to one of two orders, Saprolegniales and Peronosporales. The order Peronosporales contains *Phytophthora* species and a number of other very important plant-pathogenic genera, including the genus *Pythium*.

P. infestans has worldwide distribution, but most severe epidemics occur in areas with frequent cool, moist weather.

In Hawai'i, late blight is a common disease of tomatoes at upper elevations where the weather pattern is predominantly cool and moist during the winter months. For example, the disease occurs on Hawai'i from Hilo to Volcano and even in shadehouse-grown tomatoes in locations such as the Opihikao region near sea level. However, the epidemics tend to coincide with cool, moist



Brown, blighted tomato fruits in a garden near Hilo, Hawaii in April 2007, caused by the late blight plant pathogen *Phytophthora infestans*. All photos by S. Nelson, unless noted otherwise.

winter weather patterns at these locations. Late blight is not as likely to occur in warmer, more arid regions of the state. The other important host for *P. infestans* is potato. In the early to mid-1990s, a late blight epidemic struck experimental potato plantings at Kunia, O'ahu, causing widespread crop loss in a matter of days (S. Nelson, unpublished).

The host range of *P. infestans* is mainly limited to solanaceous crops, including tomato, nightshade (*Solanum nigrum*), and potato. Sweetpotato (*Ipomea batatas*) is not a host for late blight.

Many strains of *P. infestans* have been reported in the United States and worldwide. They vary genetically for virulence and have been able to overcome previously resistant plant varieties (e.g., potatoes), and they also pose the threat of developing resistance to certain types of fungicides.

P. infestans infects all aboveground parts of susceptible plants at any stage of plant development.

The pathogen is heterothallic (vs. homothallic), having two compatibility mating types designated as A1 and A2. Whenever these two mating types occur together in the same plant tissue, sexual reproduction between them produces oospores; otherwise, only asexual sporangia are produced. Until the early 1980s, A1 was the predominant mating type recovered from all regions of the world, except central Mexico. A2 isolates are now found in all potato-growing areas of the world. Due to the absence of oospores in samples of tomatoes with late blight in Hawai'i examined by the author, it is likely that mating type A1 is responsible for late blight epidemics on tomato here.

Summary of the late blight disease cycle

Dissemination: Sporangia or mycelial fragments are dispersed from infected plant organs by winds and/or splashing raindrops or wind-driven rain.

Inoculation: Sporangia or mycelial fragments land on

Table 1. Reported plant hosts worldwide of the plant pathogen *Phytophthora infestans* (after Erwin and Ribeiro 1996)*.

Scientific names (common names)

Acer sp. (maple)
Anthocercis viscosa R. (anthocercis)
Aster thomsonii Clarke (aster)
Atropa belladonna L. (deadly nightshade)
Bupleurum maddenii Clarke (thoroughwax)
Capsicum annuum L. (red pepper)
Datura spp. (2 species) (datura)
Erigeron multicaulis DC (fleabane)
Galingsoga parviflora
Geranium nepalense Sweet (franebill)
Hyoscyamus spp. (2 species) (henbane)
Ipomoea spp. (2 species) (morning-glory)
Lycium spp. (4 species) (matrimony vine)
Lycopersicon esculentum Mill. (tomato)
Mandragora officinarum L. (mandrake)
Mirabilis jalapa L. (four o'clock)
Nicandra physalodes (L.) Gaertn. (apple of Peru)
Nicotiana spp. (2 species) (nicotiana)
Nolana humifusa (Gouan) Johnst. (nolana)
Petunia spp. (2 species) (petunia)
Physalis spp. (2 species)
 (Chinese lantern, tomatillo, ground cherry)
Polygonum alatum Buch-Ham (smartweed, knotweed)
Rumex acetosa Linn. (garden sorrel)
Salpichroa organifolia (Lam.) Baill. (cock's eggs)
Salpiglossus spp. (3 species) (painted tongue)
Schizanthus spp. (3 species) (butterfly flower)
Solanum spp. (47 species)
Tilia sp. (lime tree)
Withania somnifera (L.) Dun.

*Host-specific strains or races of *P. infestans* are common. It is highly unlikely that any given isolate or population of the pathogen would be capable of infecting and causing disease on all of the hosts listed here. That a given isolate or population of the pathogen would show decided host preference or be host-specific is much more likely, meaning that in reality the host range of a given isolate or population of *P. infestans* would be more restricted than suggested above.

susceptible host organ(s).

Infection and pathogen development: Sporangia germinate directly via germ tubes and penetrate a plant organ, or sporangia release motile zoospores which in turn encyst on host organs and penetrate the tissues via a penetration peg.

Symptom and disease development: Mycelium of the pathogen penetrates cell walls directly and ramifies intercellularly throughout host tissues, rapidly destroying them and leading to the development of the

characteristic necrotic late blight symptoms.

Sexual reproduction is rare in nature; more commonly, asexual reproduction occurs. Sporangiophores bearing asexually produced zoospores form on diseased tissues at a relative humidity of 91–100% and a temperature range of approximately 38–79°F with an optimum temperature between 64 and 72°F.

P. infestans survives in plant debris or on volunteer tomato plants and on perennial weeds such as nightshade; where both mating types are present (A1 and A2), *P. infestans* generates the thick-walled oospores that are longer-term survival propagules.

Dispersal of the pathogen is by wind, rain, or human-assisted via movement of infested or infected materials such as seed or tools.

Daytime temperatures between 60 and 70°F, night temperatures between 50 and 60°F, and relative humidity near 100% are the ideal conditions for infection and spread of late blight disease.

Predisposing factors include cool, wet weather and high relative humidity, and large, densely planted crops of tomato.

Disease symptoms and signs

On tomato leaves

Lesions begin as indefinite, water-soaked spots that enlarge rapidly into pale green to brownish-black lesions and can cover large areas of the leaf. During wet weather, lesions on the abaxial surface of the leaf may be covered with a gray to white moldy growth (not to be confused with powdery mildew disease). On the undersides of larger lesions, a ring of moldy growth of the pathogen is often visible during humid weather. As the disease progresses, the foliage turns yellow and then brown, curls, shrivels, and dies. The late blight symptoms are distinct from and should not be confused with symptoms of powdery mildew disease, the spores of which appear usually on the upper leaf surface of tomato.

On tomato petioles and stems

Lesions begin as indefinite, water-soaked spots that enlarge rapidly into brown to black lesions that cover large areas of the petioles and stems. During wet weather, lesions may be covered with a gray to white moldy growth of the pathogen. Affected stems and petioles may eventually collapse at the point of infection, leading to death of all distal parts of the plant.



Initial symptoms of late blight of tomato on tomato leaves: a rapidly expanding, grayish-brown blight of leaves, petioles and stems. Blighted areas on leaves may have irregular shapes. Disease onset and progression are usually very rapid. Blighted leaves turn yellow and may become curled and deformed within days of becoming infected.



A sign of the pathogen *Phytophthora infestans* can be visible as powdery, whitish rings around the margins of the blighted areas. The whitish material consists of mycelia and zoospores of the pathogen.



Elongated, blackened lesions appear on tomato branches and stems.



Elongated, blackened lesions appear on tomato branches and stems. Stems, petioles and leaves may collapse. The pathogen may produce a sheen of white mycelium and spores on the surface of these blighted tissues (right).



Infected tomato fruits turn greasy, olivaceous-brown, decay, and can shrivel up and fall off the plant and never ripen. Such infected fruits are not fit for human consumption. They should be removed from affected gardens and destroyed. The fruit damage that appears in this photograph can occur in a few days or less under the right weather conditions.



A garden planting destroyed by late blight. Virtually all of the tomato plant leaves in a garden can be destroyed within a week's time during weather that is favorable for late blight disease development. Avoid planting tomato plants in large groups where plant diseases have a history of limiting tomato production.



A young tomato seedling with leaf, petiole and stem symptoms of late blight. The leaf and petioles collapsed, and the stem of the plant is blackened by the disease. The affected plant was growing in a commercial tomato greenhouse near 'Opihikao on the island of Hawai'i in February, 2008.



Sporangia and sporangiophores of *Phytophthora infestans*, highly magnified. These lemon-shaped sporangia may germinate directly or release swimming zoospores that can infect host tissues. Two of the sporangia in the photograph appear to be transparent, and are indeed empty, having discharged their contents. It is very important to understand that this disease can kill plants in a matter of a few days.

Photo: B. Bushe

On tomato fruits

Dark, olivaceous greasy spots develop on green fruit; a thin layer of white mycelium may be present during wet weather.

Crop damage

This disease can spread rapidly during cool, rainy weather, killing plants within a few days and causing total crop loss. Effects on the plant include extensive defoliation, reduced photosynthetic leaf area, loss of plant vigor, plant death, loss of fruits and reproductive capacity, and loss of seeds.

Plant-pathogenic species in the genus *Phytophthora* affect a wide range of important crops in Hawai'i:

Common name of plant (pathogen scientific name[s]; disease name[s])

Noni (*Phytophthora* sp.; black flag)

Taro (*Phytophthora colocasia*; leaf blight)

Pineapple (*Phytophthora cinnamomi*, *Phytophthora parasitica*; heart rot, root rot)

Papaya (*Phytophthora palmivora*; fruit blight, stem blight, root rot)

Coconut (*Phytophthora katsuriae*; heart rot)

Potato (*Phytophthora infestans*; late blight)

Some palm species (*Phytophthora* sp.; root rot)

Citrus (*Phytophthora* sp.; stem canker, root rot)

Avocado (*Phytophthora* sp.; stem canker, root rot)

A'ali'i (*Phytophthora* sp.; root rot)

Table 2. Some fungicides for sale in Hawai'i for the year ending December 31, 2008, for controlling late blight, caused by *Phytophthora infestans*, on tomato.

<i>Product name*</i>	<i>Active ingredient(s)</i>	<i>Formulation(s)</i>
Abound, Quadris, Heritage	Azoxystrobin (22.9%)	Flowable concentrate
Acrobat 50WP, Forum	*1	Wettable powder
Alude, Agrifos (several products), Fosphite, others	Mono- and di-potassium salts of phosphorous acid (45.8%)	Emulsifiable concentrate
Amistar	Azoxystrobin (80%)	Water dispersible granules
Applause 720, Bravo products, Concorde, Initiate 720	Chlorothalonil (54%)	Various
Basic Copper 53,	Basic cupric sulfate (98%)	Emulsifiable concentrate
Bonide copper	Basic cupric sulfate (7%)	Wettable powder/dust
Cabrio EG	Pyraclostrobin (20%)	Emulsifiable concentrate
Champ Formula 2	Copper hydroxide (37.5%)	Flowable concentrate
Disarm 480	*2	Flowable concentrate
Dithane 75 DF Rainshield (plus other Dithane products) various others	Mancozeb (75%)	Water dispersible granules,
Dupont Manex, Griffin Manex	Maneb (37%)	Flowable concentrate
Dupont Mankocide	Copper hydroxide (46.1%), Mancozeb (15%)	Water dispersible granules
DuPont Manzate, Griffin Mazate	Mancozeb (37%)	Flowable concentrate
Dupont Tanos	Famoxadone (25%); Cymoxanil (25%)	Water dispersible granules
Fluoronil	Chlorothalonil (72%); Metalaxyl-M (4.4%)	Water soluble packaging
Gavel 75DF	Mancozeb (66.7%); Zoxamide (8.3%)	Water dispersible granules
Kocide products (several)	Copper hydroxide	Various
Ranman	*3	Emulsifiable concentrate
Ridomil Gold	Chlorothalonil (72%); Metalaxyl-M (4.5%)	Wettable powder
Serenade	QST 713 strain of <i>Bacillus subtilis</i> (1.34%)	Emulsifiable concentrate

*The table contains arbitrary examples of product names; more products may exist with the same active ingredients and/or with different formulations.

*1: Morpholine, 3-(3-(4-chlorophenyl)-3-(3,4-dimethoxyphenyl)-1-oxo-2-propenyl) (43.1%)

*2: Methanone, [2-[[6-(2-chlorophenoxy)-5-fluoro-4-pyrimidinyl]oxy]phenyl] (5,6-dihydro-1,4,2-dioxazin-3-yl)-,O-methyloxime

*3: 1H-Imidazole-1-sulfonamide, 4-chloro-2-cyano-N,N-dimethyl-5-(4-methylphenyl) (34.5%)

Metalaxyl: Use of metalaxyl-containing fungicides may pose a particular risk for the development of fungicide resistance in *Phytophthora infestans* populations, rendering the products potentially ineffective. Resistance to metalaxyl reportedly became a widespread problem when the fungicide was once widely used to control late blight of potatoes in the U.S. mainland.

Some locations in Hawai'i where late blight of tomato caused by *P. infestans* might occur more often include the following (these are examples based on the author's experience; other locations with similar environments are not named and certainly are possibilities):

Hawai'i: Hilo, Waimea, Volcano/Mauna Loa Estates, Glenwood, Kurtistown, Waiakea Uka, Puna district, South Hilo district, Kona mauka, Hāmākua mauka, Oceanview mauka, 'Opihikao.

O'ahu: Kunia, Kāne'ohe mauka, anywhere moist and cool.

Maui: Kula, Hāna, anywhere moist and cool.

Phytophthora infestans was the plant pathogen that destroyed the potato crop in Ireland during the 1840s, causing the Irish potato famine. The great famine had far reaching socio-economic consequences, in particular for Ireland and the USA, and for botanical sciences. This pathogen is one of the most intensively analyzed organisms in botany, the study of which allowed Anton de Bary to help spawn the emerging new science of plant pathology in the late 1800s in Europe and the United States.

Integrated pest management practices (IPM)

- The most risky range of months to cultivate tomatoes in blight-prone areas in Hawaii is from November to April. Avoid winter plantings of tomato in areas where prolonged periods of cool, wet, humid weather tend to occur. The pathogen becomes inactive during dry periods. If one is unsure about the climate for a given area, one may check the "Hawaii climate summaries" link in the References to determine if the environment in a particular area tends to favor late blight disease development.
- Select a tomato variety that reaches maturity quickly (i.e., early-bearing or short-season types). This will allow the grower to get the crop harvested as soon as possible. "Early-season" tomato varieties require about 55-67 days to reach maturity; whereas "mid-season" and "late-season" varieties require from about 68-78 days and about 79-85+ days, respectively.
- Grow tomatoes in glasshouses or in spaces where there is humidity control and the plants are covered and protected from rainfall.
- Ensure quick and vigorous tomato seedling growth through adequate and supplemental plant nutrition. Silicate-containing fertilizers may increase pest resistance, especially in the seedling stages.
- Harvest early. If your tomatoes are nearly full size (yet green) and there is a big storm coming and you can use green tomatoes, you might as well harvest them.
- Stake up tomato plants, especially indeterminate types. Keep tomato stems and branches away from the ground.
- Plant blight-resistant tomato varieties when they become available. Late blight-resistant tomatoes are difficult to breed and to find in seed catalogs, and they may not necessarily perform well at your location and may be very susceptible to other diseases. A search of seed company catalogs in February 2008 revealed only two tomato varieties with purported tolerance or resistance to late blight: 'Legend' (determinate, 65-68 days to harvest) and 'Juliet Hybrid' (indeterminate, 60 days to harvest).
- Intercrop tomato with non-susceptible host plants, preferably non-solanaceous plants.
- Disperse the tomato plants around the property and avoid planting them all together in one place. Use wide plant spacing to allow air ventilation of the tomato canopy, which allows wet plant surfaces to dry off most rapidly.
- Practice good crop sanitation; inspect the plants regularly for late blight disease symptoms and promptly remove diseased material from the plot or garden (carefully detach diseased leaves, stems of fruits and destroy them).
- Eliminate cull piles in the vicinity of tomato plantings.
- Use disease-free tomato transplants; inspect seedlings for symptoms and destroy diseased plants promptly.
- Protect seedlings with fungicide sprays before transplanting.
- Destroy volunteer tomato plants.
- Avoid moving through the tomato garden or field when plant foliage is wet.
- Rotate crops; avoid successive crops of tomatoes in the same location; avoid planting a new crop of tomatoes beside a diseased crop.
- Do not plant potatoes near tomatoes, or if potatoes are planted, use a blight-resistant variety.
- Orient plant rows parallel to the prevailing winds to allow breezes to move between plant rows, which allows more rapid drying of foliage and reduced relative humidity in the plant canopy.
- Time irrigation to water plants early in the day, rather than late in the day. This allows foliage and soil to dry out before evening, lessening the duration of leaf wetness and lowering relative humidity. Do not spray foliage with water; keep water off of leaves and stems (irrigate plants at ground level rather than overhead, except for foliar feeding).
- Control solanaceous weeds around the tomato garden.
- Where possible, apply fungicides on the basis of a weather-based disease forecasting system (see below) rather than on a calendar basis.
- Large-scale growers may decide to use a preventive fungicide spray regime, applying products on a calendar basis. It is best to rotate different products to avoid fungicide resistance.
- Other growers may apply fungicides as soon as symptoms are observed.
- Do not purchase diseased tomato seedlings - inspect them for symptoms first.
- Protect seedlings from nutritional stress and other pests. Potassium silicate fertilizer can help to grow seedlings that are more resistant to fungal diseases and some insect pests.



***Solanum nigrum* (nightshade) and some other solanaceous weeds in the nightshade family are potential hosts for the late blight pathogen and should be eradicated from tomato gardens.**

Tomato cultivars vary widely in their susceptibility to plant diseases. Generally, contemporary tomato hybrids have better disease resistance than the older heirloom types. Information about disease resistance is coded on the front of tomato seed packages as upper-case letters that signify disease resistance. Look for disease-resistance letters on the seed packages you purchase. The most common letters are: V = Verticillium wilt; F = Fusarium wilt strain I, FF = Fusarium wilt strain I and II, N = nematodes, T = tobacco mosaic virus, and A = Alternaria.

Late blight disease forecasting systems

Proper timing of fungicide sprays conserves resources and provides the best disease control. Late blight epidem-

ics occur within a certain temperature range when the environment becomes very moist and humid. By using accumulated severity values for weather parameters (rainfall, air temperature, relative humidity), fungicide applications can occur at just the right time to protect the plants.

Disease forecasting systems for tomato late blight allow farmers in a region to best time their fungicidal sprays. These computerized forecasting systems use regional weather monitoring stations to make fungicide recommendations for that region. The forecasting systems assume that the pathogen inoculum is probably present and that an epidemic of the disease is highly likely if the right environmental conditions coincide.

The systems predict disease development by the ac-

cumulation of various severity values for temperature, rainfall and/or relative humidity, and when a pre-determined threshold of severity values is reached, sprays are triggered. Regional modifications to the original systems have been developed.

1) **BLITECAST system**

Based on temperature, relative humidity, and rainfall, this is a regional disease forecasting system used by potato and tomato farmers in the Northeastern United States. Farmers in a region receive daily updates and spray advisories from their control centers. In the following links are tabular summaries of the BLITECAST values and advisories for three locations in Northeastern Pennsylvania during the 2007 growing season:

BLITECAST daily forecast for Northeastern Pennsylvania (2007) http://vegdis.cas.psu.edu/03LateBlight/L103C_NE.html.

2007 BLITECAST SPRAY DATES (Northeastern Pennsylvania) http://vegdis.cas.psu.edu/03LateBlight/L201M_All.html.

2) **NoBLIGHT system (Maine)**

This is similar to BLITECAST, but differs in the calculation of severity values for relative humidity; see Johnson 2005.

3) **HYRE system**

This is based on temperature and rainfall.

4) **WALLIN system**

This is based on temperature and relative humidity.

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