Plant Diseases in High Tunnels: Their Pathology and Control

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Plant pathologists describe the relationship between plant, disease, and environment with the **Disease Triangle**. Only when all three “sides” of the triangle are suitable, can a plant disease occur. Diseases will not occur in the absence of the environmental conditions necessary for the existence of the pathogen that causes them.

**Environment:** Where the plant is located and the weather conditions affecting it. Some environmental conditions favor certain pathogens over others.

**Pathogen:** The disease-causing agent. Common disease-causing agents include:
- Fungi
- Bacteria
- Viruses
- Nematodes

**Host:** The susceptible plant that can develop disease.

Growing crops in high tunnels can prevent or reduce the likelihood of many plant diseases by preventing the pathogen from contacting the host, and by creating an environment unfavorable to disease development. Growers can make plant disease even less likely by selecting non-susceptible plants, and by controlling the environment and the contact of pathogen with plant. This chapter examines best practices for plant disease management, and also lists the most common plant pathogens of vegetables grown in high tunnels.

**Part I: Plant Disease Management in High Tunnels**

A sound disease management program should not and cannot rely on fungicides alone! Focus on maintaining plant health. This involves sound cultural practices, selection of resistant cultivars, and proper use of fungicides that are selected based on accurate disease diagnosis.

Note that many plant disorders may appear to be diseases, but are actually physiological responses to other factors. Sunscald leading to necrosis of tomato or pumpkin tissue is an example of a disorder that is not caused by a plant pathogen. Be sure to rule out environmental, nutritional, or other physiological responses before you assume a disorder is a disease.

Plant pathogens do cause diseases, though, and the grower must be prepared to manage the high tunnel environment to minimize disease, and to respond to disease if it does develop.

There are really four stages of disease management for high tunnels. Disease must be prevented, managed, and treated at each of these stages.
1. Pre-Tunnel Establishment: before the tunnel has even been constructed.
2. Pre-Season: before the growing season begins.
3. Transplant Production: usually in a separate greenhouse.
4. Crop Production: in the high tunnel.

1. Pre-High Tunnel Establishment

Disease management begins before the high tunnel is even established. Set up the tunnel and plan to operate it in such a way as to make the environment inside as inhospitable to plant disease as possible.

As noted in the “Site Selection” chapter, the tunnel should be oriented east-west to maximize sun interception. Avoid any shading at all. Maximize air flow by orienting single-bay tunnels perpendicular to prevailing winds, and multi-bay parallel to the prevailing winds. Some say the Minnesota has no prevailing winds, that the wind can and does blow strongly from any direction, but in most parts of the state, during most of the growing season, winds are coming from south, southwest, and west. So a grower orienting a single-bay tunnel along a north-south axis will be placing the tunnel more or less perpendicular to prevailing winds, but will not have maximized light interception early and late in the season.

Optimizing temperatures will help keep plants healthy, more naturally resistant to pathogens. The tunnel certainly provides a warmer environment in early spring and late in fall. In early spring, drier soil and warmer soil temperatures will help prevent root rots. Black plastic mulch can help warm soil faster and more in spring when the sun is bright but the soil is still cool.

Optimizing humidity during the growing season usually will mean keeping humidity as low as possible. Pay close attention to venting the tunnel early in the morning and late in the day, as temperatures will rise quickly once the sun is shining on the tunnel, increasing relative humidity. Later in the day, warm moist air will release dew as the tunnel cools. Minimize leaf wetness, by using drip irrigation rather than overhead.

2. Pre-Season Disease Management

Sanitation and Hygiene

Make sure high tunnel and surrounding area is weed-free and that crop debris has been removed or has completely decomposed. Disinfest all high tunnel equipment including stakes, clips, irrigation system, and any other tools or supplies used in the tunnel. A number of sanitizers/biocides are available, including:

- Quaternary ammonium (e.g. Greenshield)
- Household bleach
- Hydrogen dioxide (e.g. Oxidate, ZeroTol)
- Chlorine dioxide (e.g. Selectocide)

Follow label instructions in using any sanitizer.

Crop Rotation

Plan a crop rotation or cropping sequence. Especially for growers with only one tunnel, this will be very challenging, but it’s needed to break pathogen lifecycles and improve soil health.
Grafting onto Resistant Rootstocks
Where it is simply impossible to not plant the same crops year after year into the same high tunnel, one strategy is to graft desired cultivars onto resistant rootstocks. This is commonly done for tomatoes.

Cover Crops as Biofumigants
Another possibility is the use of biofumigant cover crops. These crops would be sown over part or all of the tunnel area. When the cover crop dies and senesces, chemicals are released that inhibit the growth of plant pathogens, nematodes, and/or some weeds.

Biofumigant plants include:
- Brassicas: mustards, rapeseed, oilseed radish
- Sudangrass and sorghum-sudangrass hybrids
- Forage pearl millet
- Marigold
- Flax

Disease-Resistant Cultivars
Disease resistant cultivars are the first line of defense against plant pathogens. Use of disease-resistant plants can often delay the onset of the disease and slow disease development (for example, plants may retain leaves longer), but most disease-resistant cultivars are not truly immune, and can become severely infected by the end of the season.

Certainly, planting disease-resistant cultivars can reduce the number of fungicide applications. Planting disease-resistant cultivars also should eliminate or at least reduce the amount of pathogen available to initiate disease in other plants.

3. Transplant Production
Hot Water Seed Treatment
Start transplants from disease-free seed. If there is a chance seed could bear pathogens, use a hot-water seed treatment. This will kill most bacterial pathogens on and within seeds. Hot-water treatment is suggested for eggplant, pepper, tomato, carrot, spinach, lettuce, celery, cabbage, turnip, radish and other brassicas. It is not for use on cucurbit seed or other large seeded crops. Seed can be damaged!

Different seeds have different requirements for time intervals and water temperatures. The process is very specific to each type of seed, and treating seeds in the wrong manner can kill them.

<table>
<thead>
<tr>
<th>Seed type</th>
<th>Water temperature</th>
<th>Minutes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brussels sprouts, eggplant, spinach, cabbage, tomato</td>
<td>122°F</td>
<td>25</td>
</tr>
<tr>
<td>Broccoli, cauliflower, carrot, collard, kale, kohlrabi, rutabaga, turnip</td>
<td>122°F</td>
<td>20</td>
</tr>
<tr>
<td>Mustard, cress, radish</td>
<td>122°F</td>
<td>15</td>
</tr>
<tr>
<td>Peppers</td>
<td>125°F</td>
<td>30</td>
</tr>
<tr>
<td>Lettuce, celery, celeriac</td>
<td>118°F</td>
<td>30</td>
</tr>
</tbody>
</table>
Practice good sanitation in the greenhouse

If you have a greenhouse and grow your own transplants, these are guidelines to follow. If you purchase transplants from another grower, make sure your supplier is following them as well.

Use new or sanitized plug trays or flats, and pathogen-free mixes. To sterilize potting mix, use aerated steam at 145°F to 160°F for 30 minutes. Before planting, sanitize all equipment. Greenhouse floors should be solid, and seedling trays should not rest on the floor. Avoid having ornamentals and vegetables in the same greenhouse.

Overhead irrigation is the norm in seedling production; make sure to water early in the day. Good air circulation and ventilation is essential. Avoid clipping, pruning, or injuring transplants, as the injury sites provide an entry point for the bacteria.

Scout greenhouses regularly. Rogue out diseased plants and surrounding “asymptomatic” ones. Maintain a regular spray program in the greenhouse. The seedling stage is no time for taking chances.

Limit movement of personnel and equipment between greenhouses. After the seedlings have been transplanted out, take the time to thoroughly clean the greenhouse, benches, and equipment.

4. Crop Production

Maintain good weed control inside and outside the high tunnel. Weeds are hosts for many crop plant pathogens.

Use plant spacings that will allow air circulation, and trellis as needed to maintain air flow between plants. After fruit-set, remove any senescing leaves below fruit and remove them from the tunnel. Don’t have a cull pile right outside the tunnel. The farther away, the better, and no cull pile at all would be best.

Ideally, and typically, high tunnels in Minnesota have drip irrigation. However, if a tunnel has only overhead irrigation, water early in the day and avoid working with the plants until they have dried. Consider installing drip tubing for the next season! So may of the benefits of high tunnels come from not having water contact the leaves and fruits.

Raise and lower the tunnel sides as needed to regulate temperature and relative humidity. Many plant pathogens don’t need free water to flourish, instead multiplying when there is high relative humidity.

Hygiene

Don’t smoke in high tunnels or greenhouses. Require employees to wash their hands frequently, between rows and between high tunnels. (Wearing gloves won’t solve the problem of pathogen transfer from plant to plant, unless gloves are changed as often as hands would be washed.) Disinfect equipment frequently, and minimize movement between tunnels. Set up a hand and equipment cleaning station convenient to the high tunnels.
Scouting and Treatment of Diseases
Scout for diseases and other pests on a weekly basis. Keep complete records of all production practices, including pesticide applications, but also of fertilization or fertigation, harvest, temperatures inside and outside the tunnel.

Fungicides can often be applied as soon as disease is detected. Biological products need to be applied preventatively.

What constitutes legal use of pesticides in a high tunnel?
In Pennsylvania, the guidelines are:
- That the crop must be on the pesticide label.
- The position of the tunnel sides determines whether to use greenhouse or field pesticides. If the high tunnel sides are down, the application is considered a greenhouse application. If the sides are up, it’s a field application.
- Some pesticides have a label that precludes their use in greenhouses. Even if the sides are up, these should not be used in high tunnels.

Part II: Diseases of Concern in High Tunnels

Leaf Mold on Tomato (*Fulvia fulva*)

Symptoms
- White spots that rapidly enlarge and become yellow on upper leaf surface.
- Can be confused with early powdery mildew symptoms.

Sources of Inoculum
- Persists in plant debris and volunteer tomatoes inside and outside the tunnel.
- Soil (conidia and sclerotia), contaminated seed.

Secondary spread
- Spores are readily blown throughout the high tunnel on the wind.
- They can also be spread by workers, tools, and insects.

Disease Development
- Highly dependent on high relative humidity and temperature.
• Conidia germination requires RH > 85%; optimal temperature 68 to 77°F.
• Conidia can survive at least one year in the soil.
• Disease rarely occurs below 50°F.
• Numerous strains exist.

Early Blight on Tomato and Potato (*Alternaria tomatophila*)

Symptoms

• Leaf lesions often develop on mature foliage and first appear as irregular, dark brown to black dead spots. Larger lesions have a characteristic concentric ring pattern.
• Stem lesions occur at any age, and are initially small, dark and slightly sunken, then enlarge and form concentric rings, usually at point of stem attachment. Can involve the entire upper portion of fruit, which can be infected at green or ripe stage through growth cracks or other wounds. Infected fruit often drop before mature.

Disease Development

• Heavy dews, rain, or overhead irrigation needed to provide the free water the pathogen requires.
• Optimum temperature for development: 82° to 86°F for 2 to 3 days, but early blight can occur at temperatures ranging from 42°F to 93°F.
Late Blight on Tomato or Potato (*Phytophthora infestans*)

**Symptoms:**
- Water-soaked, olive-brown to black lesion.
- White sporulation on the underside of the leaf after periods of high humidity or moisture.

**Disease Development**
- Each lesion can produce 100,000 to 300,000 sporangia per day, so a late blight infection quickly becomes an epidemic.
- Optimum temperatures 60 to 75F day; 50 to 60F night

**Sources of Inoculum**
- Requires a living host including: tomato, potato, pepper, eggplant, petunia (avoid transplants and bedding plants in greenhouse) nightshade weeds
- Management begins with monitoring for and eliminating volunteers and removing any cull piles!

**Powdery Mildew** (*Podosphaera spp.*, *Erysiphe spp.*)

Although powdery mildew is quite a common pest in horticulture, until recently, it was not found in the United States or in Canada. It was introduced only in the 1990s. Now that it’s here, growers have to deal with it. It has a wide range of hosts that may be grown in high tunnels, including rosemary, bedding plants, tomato, and eggplant.
While keeping leaves and fruit dry is helpful in prevention of many plant diseases, powdery mildew is able to infect even dry tissue. Only high relative humidity, above 50%, is necessary. Optimum temperature range for the pathogen is from 68-86°F. Without excellent ventilation to control temperatures and humidity, a high tunnel can be very conducive environment for this disease.

**Gray Mold (Botrytis cinerea)**
Botrytis has a wide host range and is considered a “disease of opportunity” that can be managed with cultural and environmental methods. Optimum conditions: 65-75°F, high relative humidity and overhead irrigation. Temperatures above 82°F suppress growth and spore production.

**Sources of Inoculum:**
Persists in plant debris, other hosts in the same tunnel, including weeds inside and outside.

**Secondary spread:**
Spores are readily blown through high tunnel in wind and can also be spread by people

**Symptoms:**
Stem lesions, cankers and soft rots affect all above ground plant parts.
Often associated with wounds and senescing plant material.
“Ghost spots” on fruit result from aborted infections.

**Fusarium Wilts**
Fusarium oxysporum f. sp. lycopersici (tomato)  
F. o. f.sp. melongenae (eggplant)  
F. o. f.sp. vas Infectum (pepper)  
Fusarium oxysporum f.sp. cepae (onion and garlic)

**Sources of Inoculum:**
The fungus is present in all soils and is usually considered a secondary invader because it attacks plants already weakened by insects, mechanical damage, or other diseases. Fusarium is most active at high temperatures. This disease is controlled by proper crop
rotation with non-susceptible crops for four years, removal of infected plants, and planting disease-free seed.

**Secondary spread:**
Onion or garlic bulbs infected with Fusarium may decay further in storage.

**Symptoms:**

![Infected tomato stem showing brown streaks](image1.png) (Michelle Grabowski, University of Minnesota)

In tomato, oldest leaves wilt first. Wilting of the oldest leaves. If plants are infected early in the growing season, and if temperatures are high for an extended period, little or no normal fruit will be produced.

When a wilted plant is removed and the stem sliced near the soil line, a brown discoloration of the woody tissue can be seen between the pith and the outer, green part of the stem. The brown discoloration can extend to the top of the plant if wilting is severe.

![Infected onion plants](image2.png) (Howard F. Schwartz, Colorado State University, Bugwood.org)

In onion and garlic, symptoms include premature yellowing and dying of older leaves, stunting, and leaf tipburn, followed by destruction of the root system, shoot dieback, and rotting of the bulb.

**Verticillium Wilts**

*Verticillium albo-atrum* and *V. dahliae*

Verticillium has a wide host range, including potato, pepper, eggplant, strawberry, raspberry, beet, cucurbits, some crucifers, alfalfa, numerous weed species and woody plants.

Tomatoes are often grafted for disease resistance. The characteristics of the scion cultivar are maintained, while the disease-resistant rootstock provides resistance to the scion as well. Seed houses sell grafting supplies, and greenhouse operators should be able to produce grafted plants.

**Symptoms:**

Outer and older leaves droop, wilt, turn dry and become reddish-yellow or dark brown at the margins and between veins. Severely infected plants may appear stunted and flattened,
with small yellowish leaves. In tomatoes, leaves develop a yellow wedge shaped lesion on with a brown center. In a lengthwise cut of the stem near the soil line, veins are tan and the center is green. In strawberries, brownish to blue-black streaks or blotches may appear on the runners or petioles. In severe infestations rapid plant death can occur.

**White Mold/Timber rot (Sclerotinia)**

*Sclerotinia sclerotiorum*

*Sclerotinia* produces long-lived reproductive bodies, sclerotia, that reside in the soil. Sclerotia require several weeks in moist, cold soil (<39°F) to be “preconditioned.” In spring, after at least a week in moist, cool soil, at 59 to 65°F, the preconditioned sclerotia produce apothecia. For 5 to 10 days, the apothecia release infectious ascospores, right around the time the plants have grown a dense canopy.

**Symptoms:**

Older leaves of onion and garlic yellow prematurely, and die back. Eventually the root system is destroyed and the bulb rots. Inside the infected bulb small, hard, black poppy seed like fungal structures form. A white fuzzy growth may form on the outside of the bulb. In tomato, stems develop dark, watersoaked lesions on the stem. Stems eventually turn white and die.

A high tunnel left in the same place for years will probably be home to a large population of sclerotia in the soil.

**Viral Diseases**

There are no chemical treatments for plant viruses. Infected plants must be removed from the tunnel and disposed of to prevent transmission of the virus to other plants. Planting resistant cultivars is a good strategy, but resistance to some viruses is not available. Excellent sanitation, keeping tunnels weed-free, and controlling vectors, such as thrips, aphids, and cucumber beetles are the primary strategies to control viruses.
### Viral Diseases of Tomato

<table>
<thead>
<tr>
<th>Host Range</th>
<th>Tobacco Mosaic, Tomato Mosaic (TMV and ToMV)</th>
<th>Cucumber Mosaic (CMV)</th>
<th>Tomato Spotted Wilt (TSWV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmission</td>
<td>Seed and mechanical</td>
<td>Aphids</td>
<td>Thrips</td>
</tr>
<tr>
<td>Resistance</td>
<td>Available</td>
<td>Not Available</td>
<td>Limited</td>
</tr>
</tbody>
</table>

**Host Range:**
- Broad: many ornamentals and weeds

**Transmission:**
- Seed and mechanical
- Aphids
- Thrips

**Resistance:**
- Available
- Not Available
- Limited

Virus disease symptoms in tomato and squash (Michelle Grabowski, University of Minnesota)

### Viral Diseases of Cucurbits

<table>
<thead>
<tr>
<th>Host Range</th>
<th>Papaya ringspot (PRSV)</th>
<th>Zucchini Yellow Mosaic (ZYMV)</th>
<th>Cucumber Mosaic (CMV)</th>
<th>Squash Mosaic (SqMV)</th>
<th>Watermelon Mosaic (WMV)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Transmission</strong></td>
<td>aphids</td>
<td>aphids, seedborne, mechanical</td>
<td>aphids</td>
<td>cucumber beetles, seedborne, mechanical</td>
<td>aphids</td>
</tr>
<tr>
<td><strong>Resistance</strong></td>
<td>limited, cucumbers and melons</td>
<td>available, cucumbers</td>
<td>available, cucumbers</td>
<td>not available</td>
<td>limited</td>
</tr>
</tbody>
</table>

**Host Range:**
- Cucurbits
- Broad, many ornamentals and weeds
- Cucurbits
- Cucurbits, legumes, others

**Transmission:**
- Aphids
- Seedborne
- Mechanical

**Resistance:**
- Available
- Cucumbers
- Not available
- Limited