

Tomatoes in Greenhouses and High Tunnels -Disease Identification and Management-



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Major Greenhouse Crops in USA

- Crop and number of diseases:
 - *Cucumber*- 9 fungal and viral diseases
 - *Lettuce*- 7 bacterial, fungal, and viral diseases
 - ***Tomatoes*- 21 bacterial, fungal, and viral diseases**
 - *Herbs*- various plant-specific diseases

Greenhouse Tomato Production

- Very few pesticides are used in most greenhouse tomato crops, especially in the Northeastern US and Canada.
- Standard disease and pest management practices emphasize cultural, environmental, and biological approaches.
 - For organic production, rigorous disease (and arthropod) management is especially critical.

Diseases of Tomatoes in Greenhouses and High Tunnels

- Diseases of Propagation
- Diseases of Production

Diseases of Production

- Fungal Diseases
- Bacterial Diseases
- Viral Diseases
- Physiological (Abiotic) Diseases

Key Diseases of Greenhouse Production

- Common Diseases:
 - Botrytis
 - Powdery Mildew
- Potential Diseases:
 - Bacterial Diseases (e.g., Canker, Spot, and Speck)
 - Viral Diseases (e.g., ToMV / TMV**, TSWV, CMV)
 - *Cladosporium* Leaf Mold **
 - Early Blight
- Occasional Diseases:
 - Late Blight
 - Septoria Leaf Spot
 - Fusarium and Verticillium Wilts**

** Usually not problems with newer varieties since resistance is available.

Common Diseases

- Botrytis (Gray Mold)
- Powdery Mildew

Botrytis (Gray Mold)

- Causal Agent: *Botrytis cinerea* (fungus)
- Background:
 - Very wide host range, including many greenhouse crops.
 - “Disease of opportunity” that can be managed with cultural and environmental methods.
 - Optimum conditions: 65°-75° F, high RH, and overhead irrigation.
 - Temperatures above 82° F suppress growth and spore production.

Botrytis (Gray Mold) cont'd:

- Sources of Inoculum:
 - Persists in plant debris, other hosts growing in the same house, weed hosts inside and outside the greenhouse, and as sclerotia in soil.
- Secondary Spread:
 - Spores are readily blown throughout the house on air currents and through worker activities.

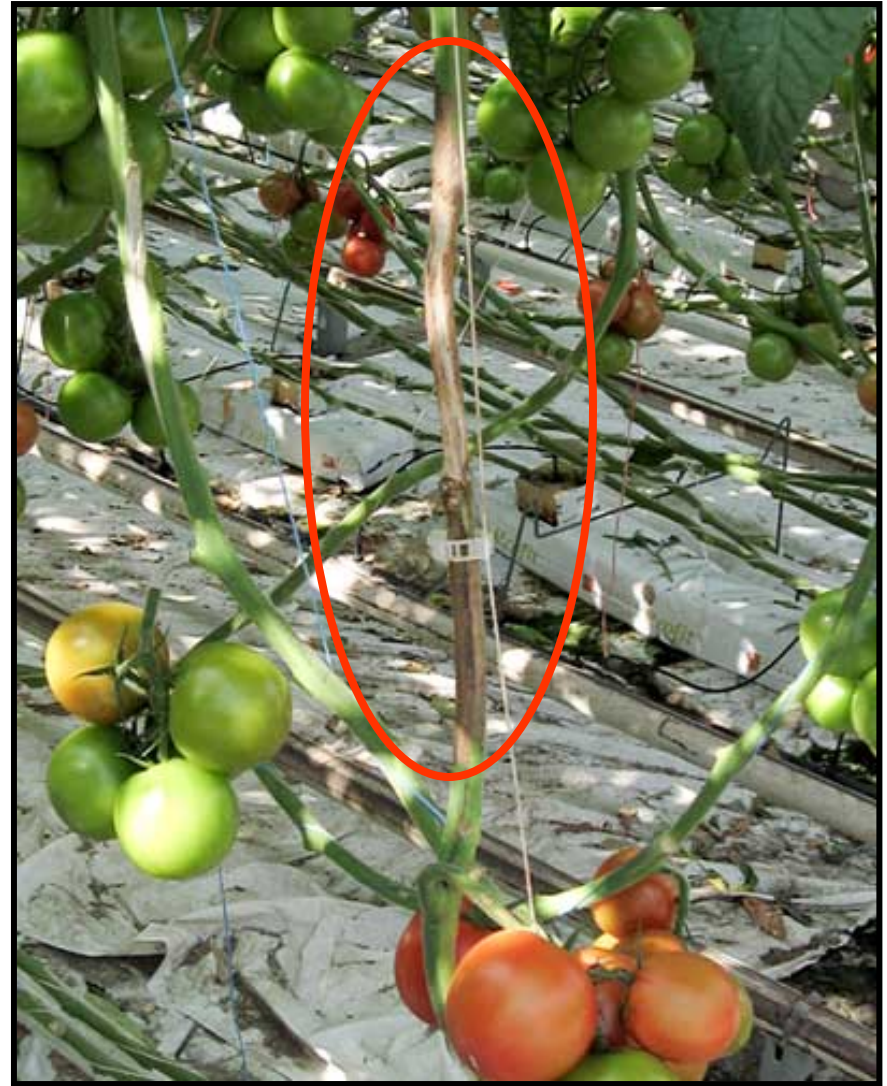
Botrytis (Gray Mold) cont'd:

- Symptoms:
 - Can infect all aboveground parts of the plant.
 - Often associated with wounds and senescing plant parts.
 - Infections are characterized by the fuzzy, gray growth of the fungus (*Common Name= Gray Mold*).
 - Stem lesions and cankers.
 - Soft rots of the stem end of fruit.
 - Ghost spots result from aborted infections of the fruit.

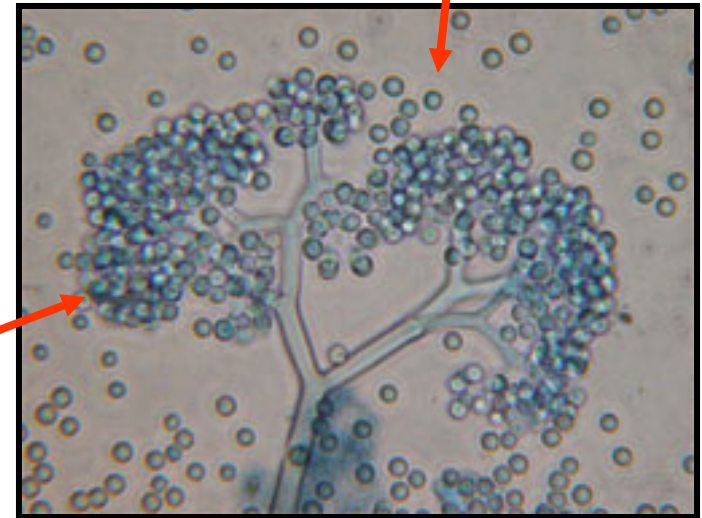
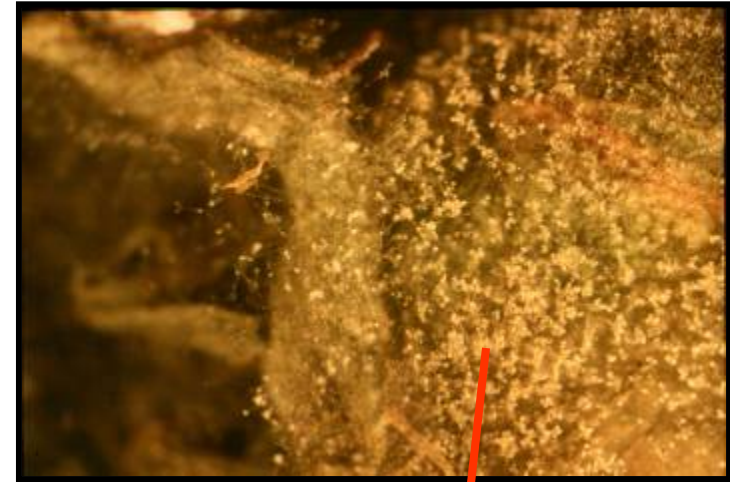
Botrytis Stem Cankers



Botrytis Stem Canker



Botrytis: Prolific Spore-Former



Botrytis spores

Masses of gray spores form under conditions of high humidity.

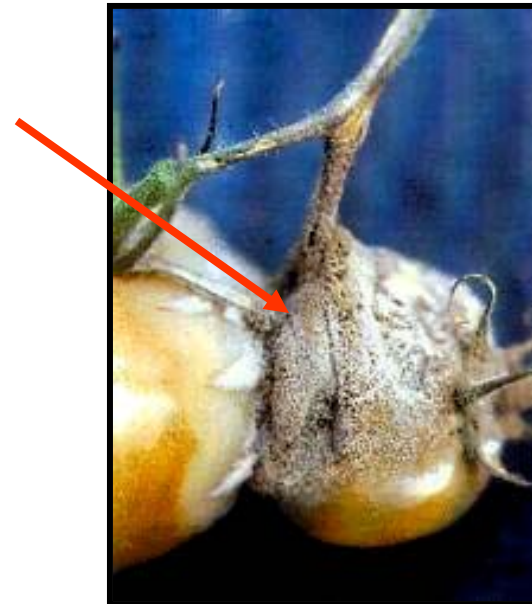
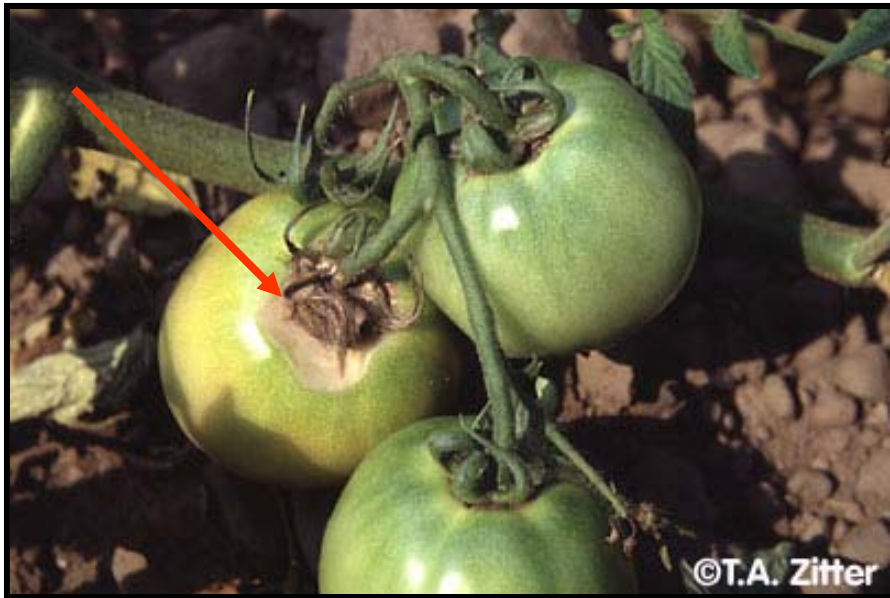
Botrytis- Fruit Symptoms



Readily invades wounds, including growth cracks.



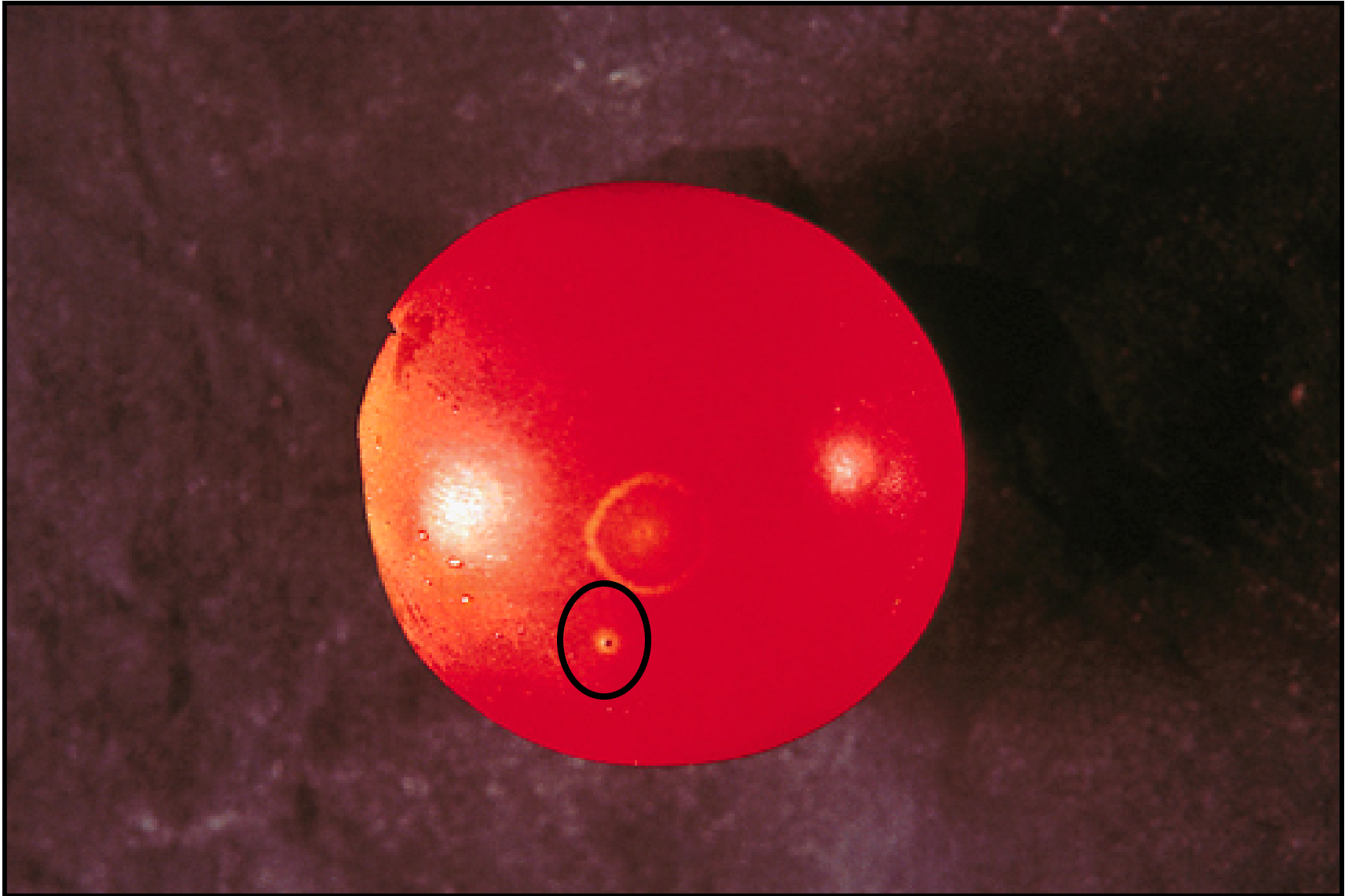
Botrytis- Fruit Infections (Stem-End)



Botrytis- Ghost Spots



Botrytis- Ghost Spots



Powdery Mildew

- Causal Agent: *Oidium neolycopersici* (fungus)
- Background:
 - First identified in greenhouse tomatoes in Connecticut in 1995.
 - Introduced into the US and Canada in the 1990's.
 - Wide host range (e.g., rosemary, pepper, eggplant, and many bedding plants).
 - Optimum conditions: RH greater than 50% (optimum RH > 90%) and temperatures ranging from 68-86 °F.
 - Free water on leaf surfaces not necessary for infection.

Powdery Mildew (cont'd):

- Sources of Inoculum:
 - Because of the wide host range, this fungus probably survives on other hosts or volunteer tomato plants inside or outside the greenhouse between production cycles.
- Secondary Spread:
 - Spores are readily blown throughout the house on air currents and through worker activities.

Powdery Mildew (cont'd):

- Symptoms:
 - First appear as pale green or chlorotic areas on the upper leaf surface.
 - Diagnostic, diffuse, white powdery patches can develop on both leaf surfaces.
 - Often not as powdery or fluffy as powdery mildews on other hosts.
 - Appears to be more aggressive than other powdery mildews.
 - Once leaves are infected, they quickly brown and shrivel on the plant.

Powdery Mildew

Chlorotic lesions are initial symptoms of infection.



Powdery Mildew



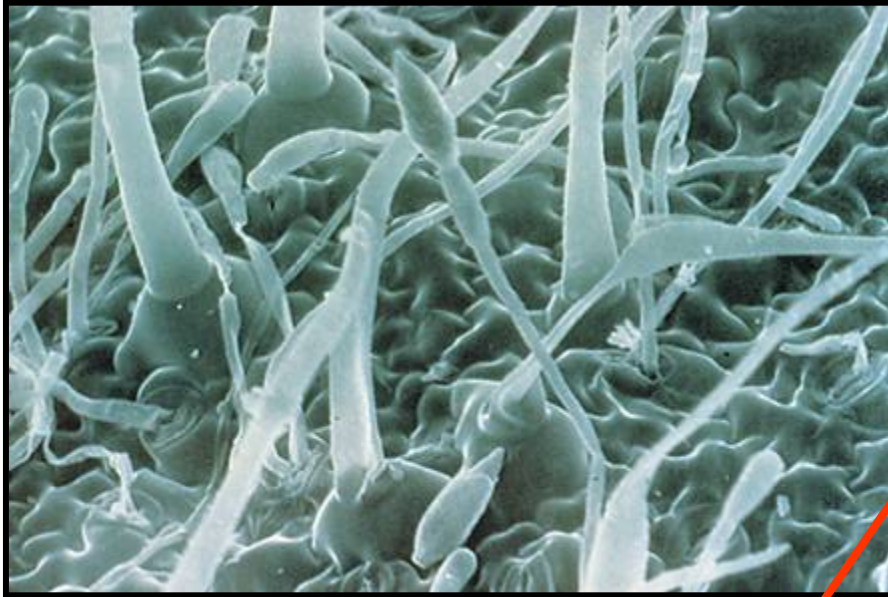
Powdery Mildew



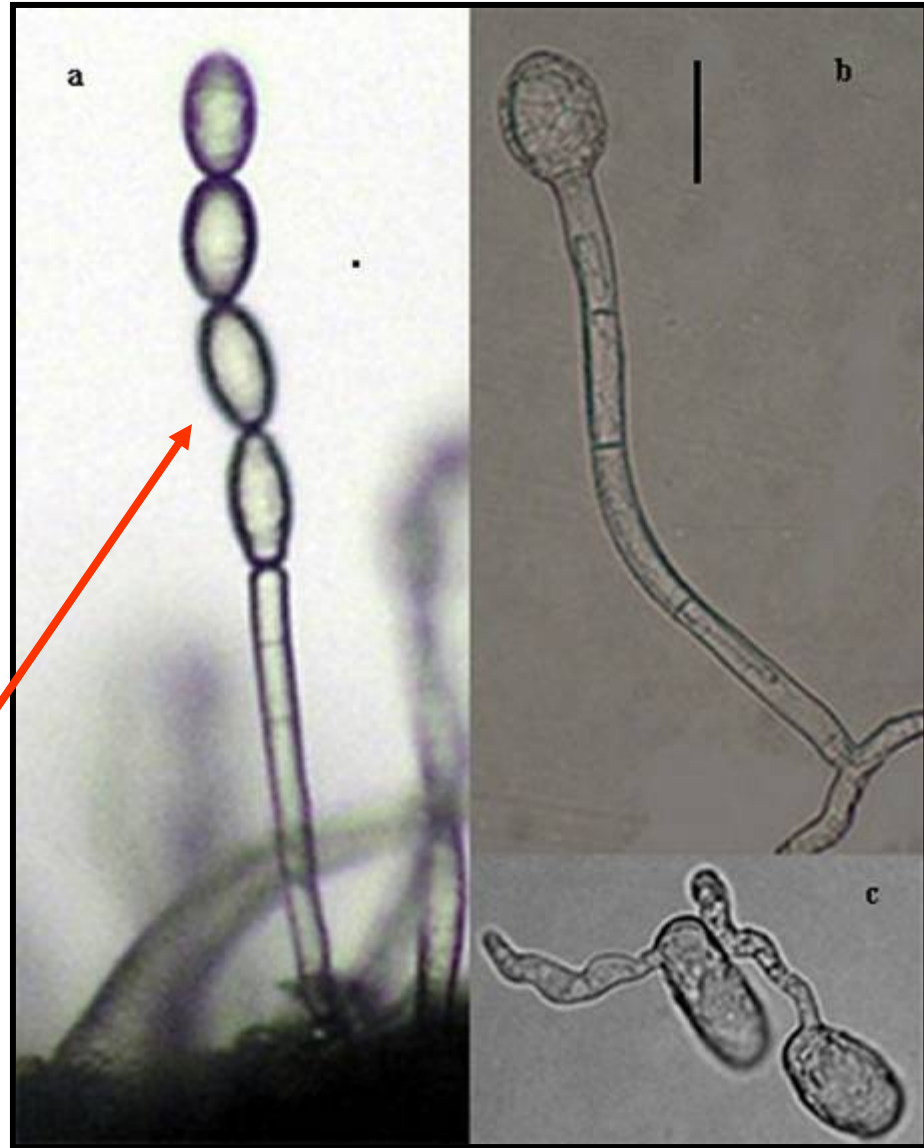
Powdery Mildew



Powdery Mildew



Chains of conidia (spores)



Potential Diseases:

- Bacterial Diseases

- Bacterial Canker
- Bacterial Spot
- Bacterial Speck

- Viral Diseases

- Tobacco/Tomato Mosaic Virus (TMV / ToMV)
- Tomato Spotted Wilt Virus (TSWV)
- Cucumber Mosaic Virus (CMV)

- Fungal Diseases

- *Cladosporium* Leaf Mold
- Early Blight
- Late Blight

Bacterial Diseases

- Bacterial Canker
- Bacterial Speck
- Bacterial Spot

Bacterial Canker

- Causal Agent: *Clavibacter michiganensis* pv. *michiganensis*
 - Optimum conditions are warm temperatures (85-89°F) and overhead-irrigation.
- Sources of Inoculum:
 - This organism is seedborne (on the surface and within the seed coat)-- 1% seed transmission ~ 100% infection.
 - Also introduced on contaminated equipment.

Bacterial Canker (cont'd):

- Sources of Inoculum (cont'd):
 - Can survive for short periods in soil, weeds outside the greenhouse, and on greenhouse structures and equipment.
 - Can be present on symptomless plants.
- Secondary Spread:
 - Irrigation, contaminated equipment, and workers' hands.

Bacterial Canker (cont'd):

- Symptoms: Plant
 - Lesions or cankers can develop on any portion of the plant, including the fruit, or may result in a general wilt or decline of the plant.
 - First symptoms usually appear as a wilting of lower leaves.
 - Light to dark brown streaks develop on stems.
 - When the stems are split longitudinally, they have a darkened center and a mealy consistency.

Bacterial Canker (cont'd):

- Symptoms: Fruit
 - Fruit infection is more common in greenhouse-grown than in field-grown tomatoes.
 - *May be confused with speck or spot.*
 - Diagnostic feature of bacterial canker fruit spots is a distinct white halo (“bird’s-eye spots”).
 - Spots are raised with brown centers and surrounded by snow-white haloes.
 - White halos may disappear as the fruit ripens.

Bacterial Canker- Foliar Symptoms



Bacterial Stem Canker



Black streaking of the
stem and bacterial ooze

Bacterial Stem Canker



Light to dark brown streaks
and cracks develop on
stems.

Bacterial Canker



Severe infection of greenhouse tomatoes with bacterial canker, showing the full manifestation of symptoms.

Bacterial Canker- Fruit Symptoms



“Bird’s-eye spots”

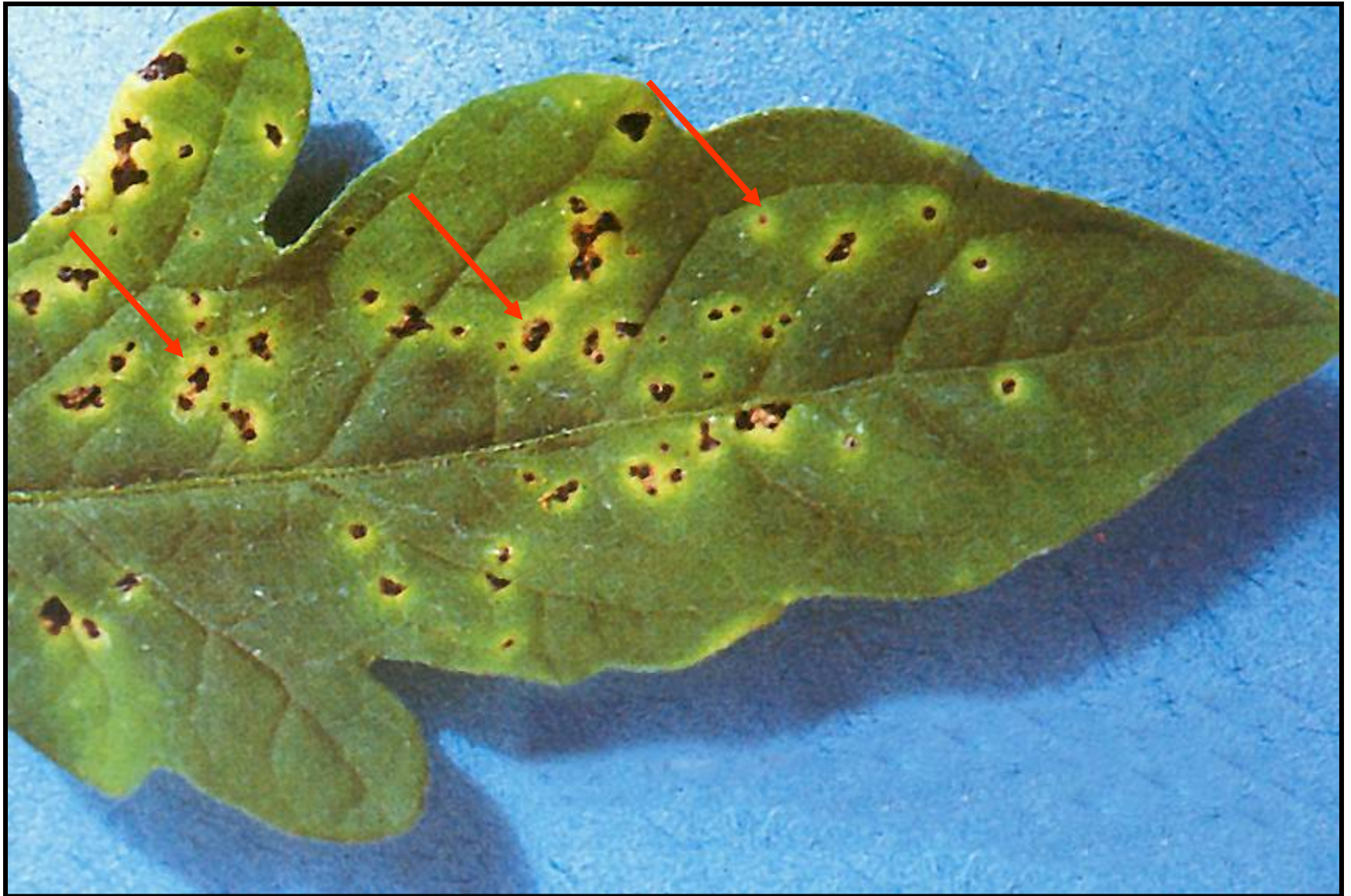
Bacterial Speck

- Causal Agent: *Pseudomonas syringae* pv. *tomato*
 - Has a lower optimum temperature (65-75°F) than Bacterial Spot.
- Sources of Inoculum:
 - Can be seedborne.
 - Introduced on infected symptomless transplants.
- Secondary Spread:
 - Irrigation, contaminated equipment, and workers' hands.

Bacterial Speck (cont'd):

- Symptoms: Foliage- *Symptoms of spot and speck are very similar on leaves.*
 - Small, water-soaked, greasy spots about 1/8 inch in diameter appear on infected leaflets.
 - Distinctive yellow haloes develop as lesions age.
- Symptoms: Fruit- Only green fruit are susceptible.
 - Green fruit: speck lesions are very small, sunken, black spots surrounded by darker green haloes.
 - Ripe fruit: spots are dark brown to black, superficial flecks.
 - The black specks persist on the fruit as they ripen but are usually very superficial and don't penetrate the fruit deeply.
 - Can often be scraped off with a fingernail.

Bacterial Speck- Foliar Symptoms



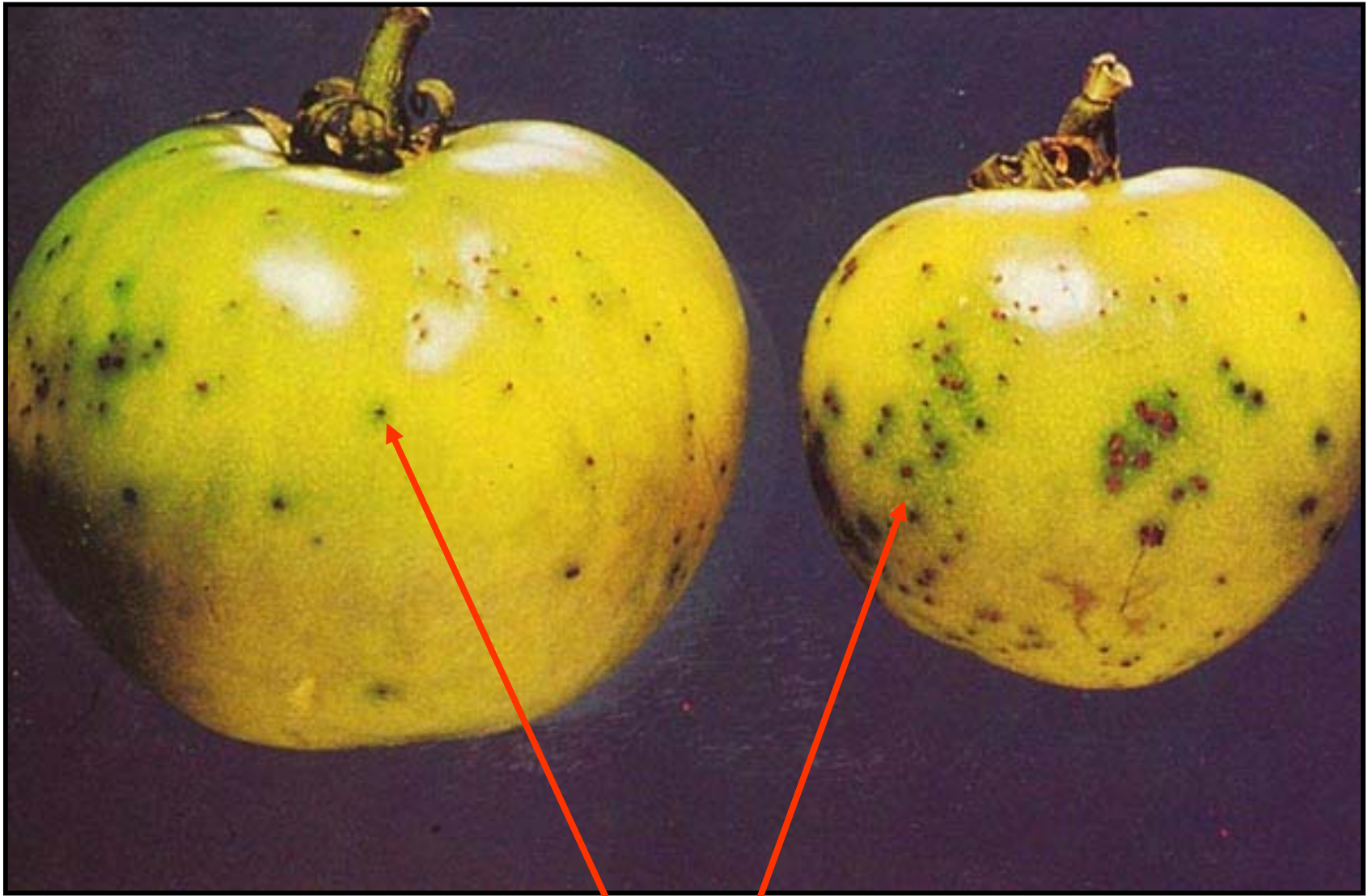
Bacterial Speck- Foliar Symptoms



Bacterial Speck- Foliar Symptoms



Bacterial Speck



Superficial Spots

Bacterial Speck- Fruit Symptoms



Superficial Spots

Bacterial Spot

- Causal Agent: *Xanthomonas campestris* pv. *vesicatoria* (formerly *X. vesicatoria*)
 - Has a higher optimum temperature (75-90°F) than Bacterial Speck.
- Sources of Inoculum:
 - Surface contaminant of tomato seeds.
 - Present on symptomless tomato transplants produced in southern states, especially when frequent rains occur in these areas before plants are pulled.
- Secondary Spread:
 - Irrigation, contaminated equipment, and workers' hands.

Bacterial Spot (cont'd):

- Symptoms: Foliage- *Symptoms of spot and speck are very similar.*
 - Tiny, circular, dark lesions.
 - Lesions may coalesce, causing blighted areas on leaves.
- Symptoms: Stems
 - Elliptical lesions that can girdle stems.
- Symptoms: Fruit- *Spot and speck are usually differentiated by symptoms on immature fruits.*
 - Only green fruit are susceptible to infection.
 - Fruit lesions begin as minute, slightly raised blisters that eventually increase in size and become brown, scab-like or corky.
 - These lesions can also be raised around the margins and sunken in the middle.

Bacterial Spot- Foliage



Bacterial Spot- Foliage



Bacterial Spot-Fruit



Bacterial Spot- Fruit



Corky lesions, often with sunken centers

Fungal Diseases

- Cladosporium Leaf Mold
- Early Blight
- Late Blight

Leaf Mold

- Causal Agent: *Fulvia fulva* (formerly *Cladosporium fulvum*)- several strains (fungus)
- Sources of Inoculum:
 - Can persist in plant residues, volunteer tomatoes inside and outside the greenhouse, and as sclerotia in soil.
 - Seed is occasionally contaminated.
- Secondary Spread:
 - Spores are readily blown throughout the house on air currents and through worker activities.

Leaf Mold (cont'd):

- Symptoms:
 - White spots that rapidly enlarge and become yellow appear on the upper surfaces of older leaves.
 - Sometimes confused with early powdery mildew symptoms.
 - Lower surfaces become covered with a velvety, olive-brown fungus growth.
 - When the disease is severe, substantial foliage is killed, and the crop is greatly reduced.
 - Spores resist drying and may live in the greenhouse several months after plants are removed.
 - Infected flowers usually die before fruit set.

Leaf Mold

Upper



Lower



Leaf Mold



Leaf Mold



Early Blight

- Causal Agent: *Alternaria tomatophilai* (formerly *A. solani*) (fungus)
- Sources of Inoculum:
 - Can be seedborne.
 - Spores are readily blown into the greenhouse from infected plants outdoors.
- Secondary Spread:
 - Spores are readily splash-dispersed with overhead irrigation and blown throughout the house on air currents and through worker activities.

Development of Early Blight:

- Favored by warm, humid conditions and 75-84°F.
- Sporulation of the fungus occurs under long wet periods or alternating wet and dry periods.
- Initial infection to sporulation takes about one week.
- Weak plants with low fertility are more susceptible.

Symptoms of Early Blight:

- Leaves:
 - Often develop on mature foliage.
 - First appear as irregular, dark brown to black, dead spots ranging in size from a pinpoint to 1/2 inch.
 - As spots enlarge, diagnostic concentric rings may form as a result of irregular growth patterns by the organism in the leaf tissue.

Symptoms of Early Blight (cont'd):

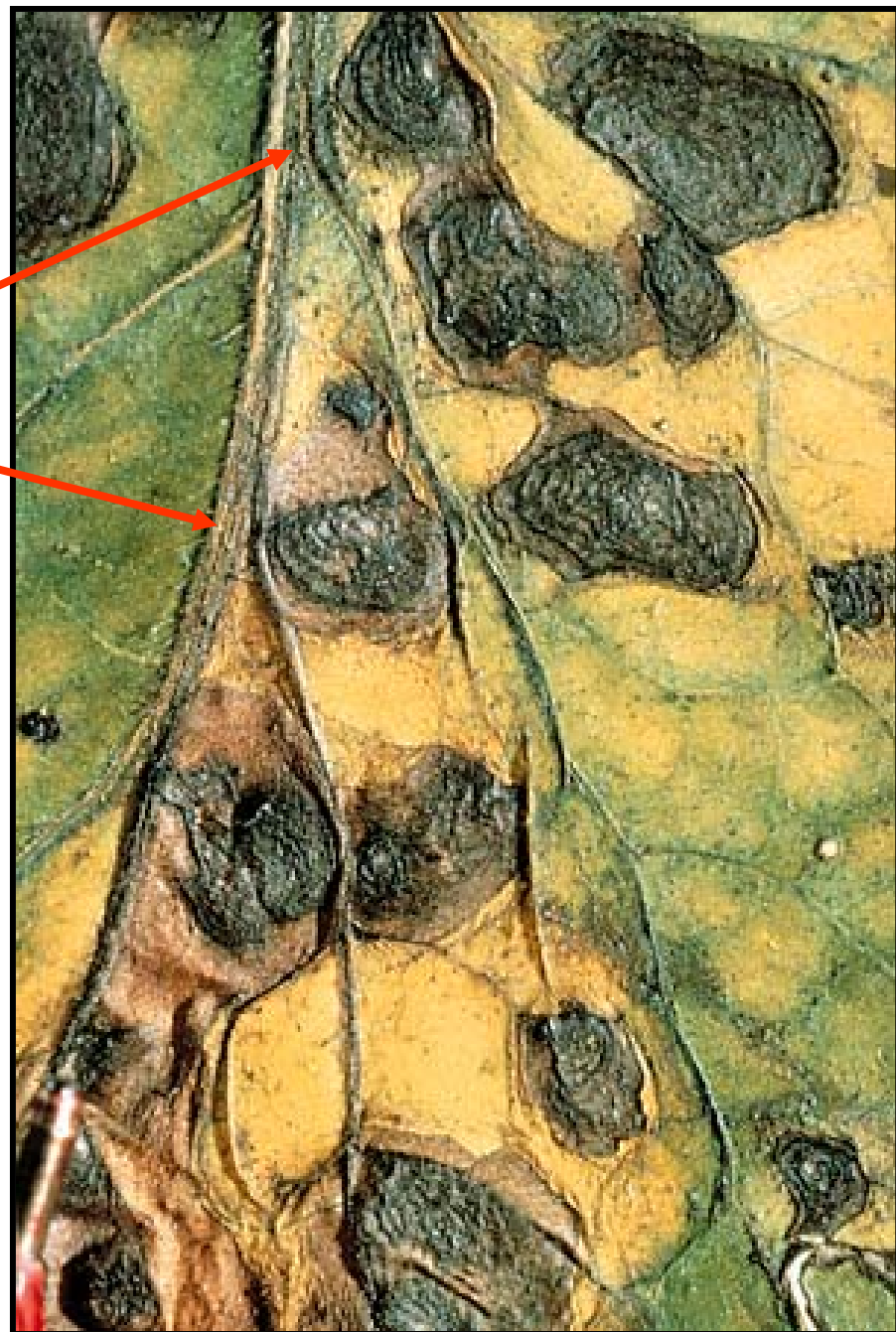
- Stems:
 - Occur at any age- small, dark, slightly sunken areas that enlarge to form circular or elongated spots with lighter-colored centers.
- Fruit:
 - Dark, leathery sunken spots, usually at point of stem attachment.
 - Can involve the entire upper portion of the fruit, often with concentric markings like those on leaves.
 - Fruits can also be infected in the green or ripe stage through growth cracks and other wounds.
 - Infected fruits often drop before they reach maturity.

Early Blight- Foliage



Early Blight- Foliage

Diagnostic
concentric rings



Early Blight- Stem Cankers



Early Blight- Fruit Symptoms



Early Blight- Fruit Symptoms



Late Blight 2009

- Unprecedented outbreak:
 - Occurred unusually early in the growing season.
 - Initiated by widespread distribution and sale of infected tomato transplants by “big box” and chain stores throughout Connecticut and the Northeast.
 - Once the infected transplants were set in the ground, they were exposed to favorable weather for disease development: cool, cloudy, windy, wet weather of May, June, and July 2009.

Late Blight

- Causal Agent: *Phytophthora infestans* (fungus-like organism, water mold)
- Hosts: tomato and potato
- Sources of Inoculum:
 - Introduced on infected transplants.
 - Spores are readily blown into the greenhouse from infected plants outdoors.
- Secondary Spread:
 - Spores are readily blown throughout the house on air currents and through worker activities.

Development of Late Blight:

- Favored by cool, moist weather.
 - Night temperatures in the 50's and day temperatures in the 70's accompanied by rain, fog, or heavy dew are optimum for infection.
 - Under these conditions, symptoms may appear on plant tissues 3-5 days after infection.
- *P. infestans* produces fruiting structures called sporangia that are visible to the naked eye as white fuzzy growth.

Development of Late Blight (cont'd):

- Up to 100,000 to 300,000 sporangia per day can be produced in an individual lesion, and each sporangium is then capable of initiating a new infection.
- Sporangia are easily dislodged and spread by irrigation, rain, wind, human activities, and equipment.
 - Can travel several miles or more.
 - Can move from field to greenhouse tomatoes.

Symptoms of Late Blight:

- Can appear on all above ground parts of tomatoes.
- Leaves:
 - Lesions vary in size from $\frac{1}{2}$ to $\frac{3}{4}$ inch or larger.
 - Water-soaked, olive brown, and sometimes have yellow margins.
- Stems:
 - Water-soaked olive-brown to black blotches or lesions that appear dark brown, dry, and superficial.
 - Range from small spots to several inches long.

Symptoms of Late Blight (cont'd):

- Fruit:
 - Develop on the stem end or on any part of green or ripe fruit.
 - Appear as dark brown, sunken lesions.
 - Lesions expand rapidly and eventually surround the entire tomato fruit.
- White sporulation of the pathogen is often visible on infected tissues after periods of high humidity or moisture.

Late Blight of Tomato



Photo courtesy of Meg McGrath

Late Blight of Tomato



Late Blight of Tomato



Late Blight of Tomato



Late Blight of Tomato



Late Blight of Tomato



Viral Diseases

- Tobacco Mosaic Virus (TMV) and Tomato Mosaic Virus (ToMV)
- Cucumber Mosaic Virus (CMV)
- Tomato Spotted Wilt Virus (TSWV)

Characteristics of Viral Diseases

<u>Virus</u>	<u>TMV/ToMV</u>	<u>CMV</u>	<u>TSWV</u>
Host Range	Broad, many ornamentals and weeds	Broad, many ornamentals and weeds	Broad, many ornamentals and weeds
Transmission	Seed and Mechanical	Aphids	Thrips
Resistance	Available	Not Available	Limited

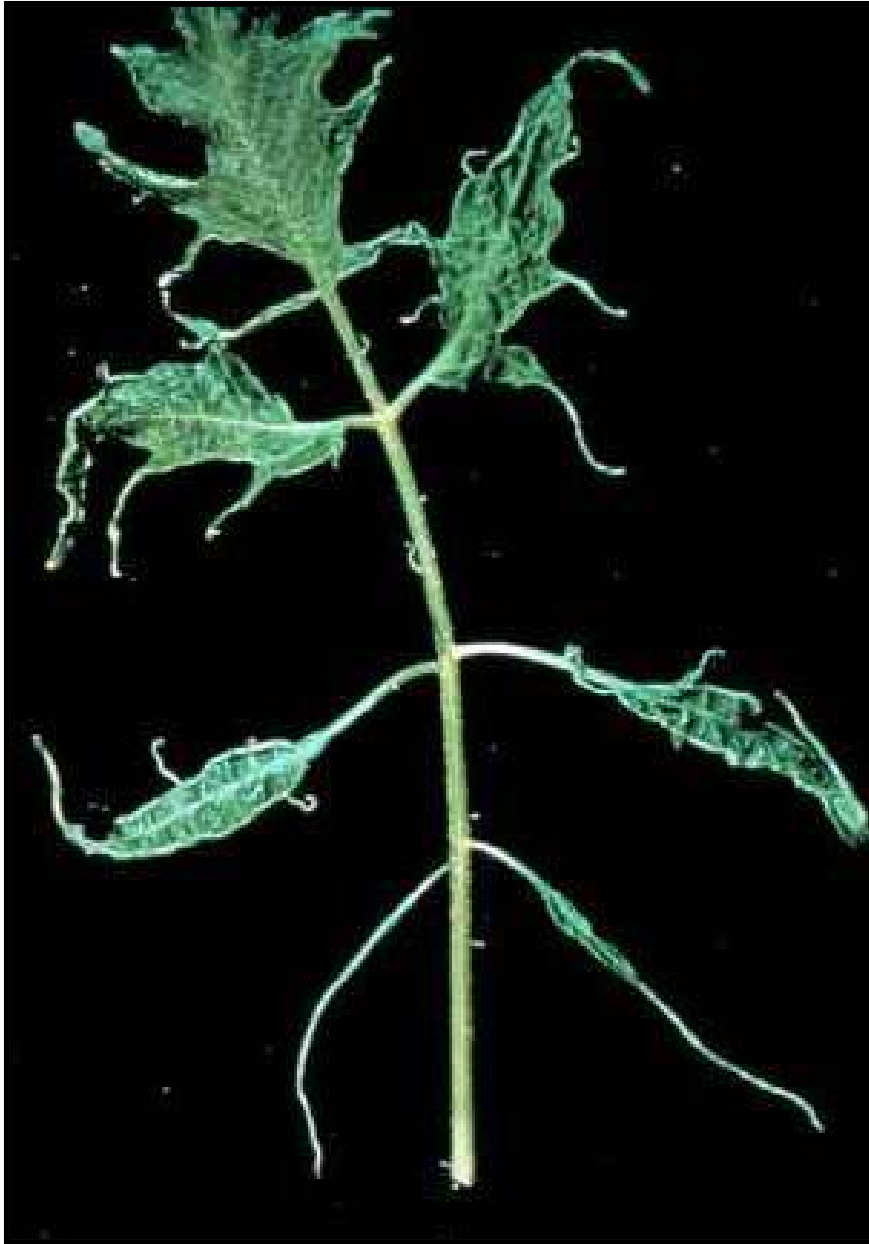
Tobacco Mosaic Virus (TMV)



Light- and dark-green mosaic pattern on leaves.



Tomato Mosaic Virus (ToMV)



Shoe-string leaf symptom.

TMV-Fruit



ToMV



Cucumber Mosaic Virus (CMV)

Fern Leaf Symptom



Aphids Transmit CMV



Photos courtesy of Leanne Pundt

Tomato Spotted Wilt Virus (TSWV)



Bronzing of leaflets

Photo UMASS

Thrips Transmit TSWV



Photo courtesy of Leanne Pundt



TSWV



Cupping and rolling of leaves



Blackened streaks on stems

TSWV- Stunting and Wilting



TSWV- Fruit Symptoms



TSWV- Fruit Symptoms



Disease Management for Tomatoes in Greenhouses and High Tunnels

- A sound management program should not and cannot rely on fungicides (pesticides) alone.
- Needs to be focused on maintaining plant health.
 - This involves sound cultural practices, selection of resistant cultivars, sanitation, and proper use of fungicides (pesticides), as determined by accurate diagnosis.

Stages of a Disease Management Program for Tomatoes in Greenhouses and High Tunnels

- Pre-Season (Pre-Production)
- Transplant Production
- Crop Production

Disease Management: Pre-Season

- Maintain a crop-free, weed-free period for ~2-4 weeks between crops.
- Disinfest all greenhouse structures and surfaces. This includes stakes, clips, dripper stakes, and other equipment.
 - Quaternary ammonium (e.g., Green-Shield, Phytosan 20, Triathlon), household bleach, hydrogen dioxide (e.g., OxiDate, ZeroTol), chlorine dioxide (e.g., Selectocide)
- Discard or steam-sterilize growing media used for crop production.
- Disinfest irrigation system.

Disease Management: Transplant Production

- Start in a separate transplant house, growth room, or growth chamber.
 - Disease and insect problems are easier to manage in a small, separate space.
 - All supplies and equipment should be new or disinfested to remove disease organisms prior to seeding.
 - [Smaller-size transplant facilities are more economical to heat, cool, and light than a small bench within a large production house.]
- When possible, choose resistant varieties and purchase hot-water treated seed.

Disease-Resistant Varieties of Greenhouse Tomato

<u>Disease</u>	<u>Resistant Varieties</u>	<u>Tolerant Varieties</u>
Fusarium Crown and Root Rot	Trust	----
Fusarium Wilt Race 1	Caruso, Stresa, Trust	Vendor
Fusarium Wilt Race 2	Caruso, Stresa, Trust	Vendor
Fusarium Wilt Race 3	----	----
Leaf Mold (<i>Cladosporium</i>)	Buffalo, Capello, Caruso (races A thru E), Cobra, Dombito, Jumbo, Match, Pink KR15 and Pink CR-864 with gene <i>Cf-5</i> , Stresa, Trend, Trust (races A thru E), Ultra Sweet & Ultra Pink with <i>Cf-7</i> , Vision, Furon and Vetomold with <i>Cf-2</i>	
Powdery Mildew (<i>Oidium</i>)	DRW 4409, Belliro (DRW 4369)	Grace, Milano
Gray Leaf Spot (<i>Stemphylium</i>)	----	----
Tobacco Mosaic Virus (TMV, ToMV)	Boa, Caruso, Cobra, Stresa, Trust	Vendor
Tomato Spotted Wilt (TSWV)	DRW 5719	----

Disease Management: Transplant Production (cont'd)

- Use new or steam-sterilized growing media for transplant production.
- It is a good idea for each grower to start their own transplants—2009 is a good example (late blight).
 - *IF purchasing transplants, be sure that the transplant producer will provide high quality plants.*
- Maintain temperatures above 60 F to avoid cat-faced fruit (embryonic flowers are formed in the plants after 4 wks).

Disease Management: Crop Production

- Keep complete records of all production activities.
- Monitor fertilizer rates, EC, pH, max-min temperatures.
- Avoid growing other crops in production houses.
- Maintain good weed control inside and outside of the greenhouse.
- Scout for diseases (insects and mites) on a weekly basis.
 - Accurately identify all diseases (insects and mites).
 - Need assistance?

Contact the Plant Disease Diagnostic
Office *or* Cooperative Extension
Service in your State

In Connecticut:

www.ct.gov/caes/

203.974.8601

Statewide Toll Free: 877.855.2237

On-Site Testing Kits

- Alert LF Kits (Neogen)
 - *Pythium* spp.
 - *Phytophthora* spp.
 - *Rhizoctonia* spp.
- ImmunoStrips (Agdia)
 - INSV
 - TSWV
 - TOSPO (INSV & TSWV)
 - CMV
 - TMV

Neogen Europe, Ltd.
www.neogeneurope.com

Agdia, Inc
Elkhart, Indiana
1-800-622-4342
www.agdia.com

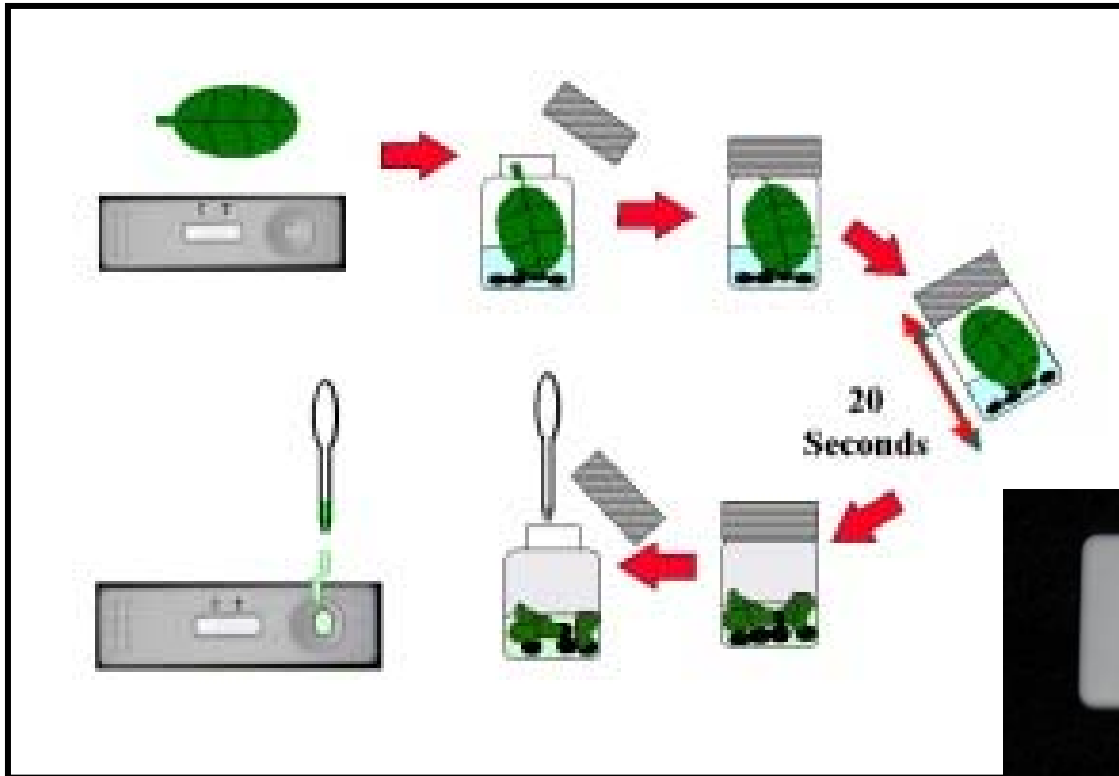
On-site Detection Kits

Agdia ImmunoStrips



On-site Detection Kits

Neogen Alert LF Kit



Disease Management: Crop Production (cont'd)

- Avoid locating cull piles in the vicinity of the greenhouse.
- Maintain adequate plant spacing for air circulation.
- Use heating and venting to reduce RH levels, esp. at night.
 - This is especially important for Botrytis and Powdery Mildew infections.
- After fruit-set, remove senescing leaves below fruit and remove from greenhouse area.
 - When removing infected plant material, place in a bag to avoid spreading spores throughout the house.
- Avoid overhead irrigation or water early in the day.
- Avoid working with plants when wet.

Disease Management: Crop Production (cont'd)

- Discourage smoking by any employees.
- Require frequent hand-washing, esp. between rows or houses.
- Disinfest equipment frequently.
- IF TMV/ToMV is detected,
 - Spray plants with whole or skim milk (5 gals /100 gals water) or dried milk (5 lbs/100 gals water) per 100 sq. yds. of plants.
 - The coat protein of the virus reacts with proteins in milk, so milk has been used to inactivate of the virus.
 - Spraying plants 1 to 24 hrs before handling has been effective in some cases.
 - *Frequent* washing of hands with milk or soap and water when handling plants is also important.

Disease Management: Crop Production (cont'd)

- Biological controls need to be applied as preventatives.
- Fungicides should be applied as soon as disease is detected.
 - Once a disease is confirmed in a greenhouse, aids to pollination and high-volume, high-pressure pesticide spraying should stop to reduce the spread of disease.

What is needed for pesticides to be legal for Greenhouse Use?

- EPA has not established definitive guidelines for pesticide use in greenhouses.
- The following guidelines are used by many states (including Connecticut):
 - Crop is on label.
 - Label does not preclude use in greenhouses.
 - For example, if label states: “Do not use in greenhouse,” or “Not for use in greenhouse,” it can’t be used.

Disease Management: Crop Production (cont'd)

Biological Controls

Must be used as protectants!

Disease	Product
Botrytis	Suppression only: -- <i>Streptomyces griseoviridis</i> strain K61 (Mycostop) -- <i>Bacillus subtilis</i> (Cease, Rhapsody, Serenade)
Early & Late Blight	-- <i>Bacillus subtilis</i> (Cease, Rhapsody, Serenade)
Powdery Mildew	-- <i>Bacillus subtilis</i> (Cease, Rhapsody, Serenade)
Bacterial Diseases	None
Viral Diseases	None

Fungicides for Botrytis*:

- Copper (Cuprofix Disperss, Kocide, and others)
- Dichloran (Botran 75-W)
- Fenhexamide (Decree 50 WDG)
- Mancozeb (Dithane)
- Hydrogen dioxide (OxiDate)
- Pyrimethanil (Scala SC)
- Rosemary and essential plant oils (Sporan)

* Important to rotate FRAC groups of fungicides

Fungicides for Powdery Mildew*:

- Copper products (Kocide, Tenn-Cop, Cuprofix Disperss)
- Horticultural oil (Ultra-Fine oil, JMS Stylet-Oil)
- Hydrogen dioxide (OxiDate)
- Potassium bicarbonate (Armicarb, Kaligreen, MilStop)
- Potassium salts of fatty acids (M-Pede)
- Rosemary and essential plant oils (Sporan)
- Sulfur (Microthiol Disperss, Micro Sulf)

* Important to rotate FRAC groups of fungicides

Fungicides for Early Blight:

- Copper Compounds (Kocide, Cuprofix Disperss, Nu-Cop, other products)
- Maneb/ Mancozeb (Maneb, Dithane)
- Propamocarb hydrochloride (Previcur Flex)
- Pyrimethanil (Scala)
- Hydrogen dioxide (OxiDate)

Fungicides for Late Blight:

- Copper Compounds (Kocide, Nu-Cop, other products)
- Fenhexamide (Decree)
- Hydrogen dioxide (OxiDate)
- Pyrimethanil (Scala)
- Maneb/ Mancozeb (Maneb, Dithane)
- Propamocarb hydrochloride (Previcur Flex)

Fungicides for Leaf Mold:

- Hydrogen dioxide (OxiDate)
- Maneb (Maneb 75DF, Maneb 80WP)
- Mancozeb (Dithane)

Pesticides for Bacterial Diseases (?):

- Copper products (Kocide, Tenn-Cop, Cuprofix Disperss, and others)
- Hydrogen dioxide (OxiDate)

