Emerging Viral and Other Diseases of Processing Tomatoes: Biology, Diagnosis and Management

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Tomatoes originated in the New World

- Tomato is a New World crop that originated in the arid lands of South America (Peru, Ecuador and Chile)
- Domestication of tomato occurred in Mexico, followed by introduction to the Old World, re-introduction to the New World and worldwide distribution and cultivation
- Diversity of tomato includes wild species and a wide range of cultivars and land races
Tomatoes are cultivated worldwide

• Today, tomatoes are grown world-wide (in 144 countries)
• Second most important vegetable crop
• Worldwide demand and production have increased substantially over the past 30 years

Cosmopolitan nature of tomato production
Is reflected by the WPTC membership

Worldwide tomato production
Worldwide cultivation of tomato exposed the New World crop to a wide range of new pathogens

• Many pathogens found tomato to be a highly susceptible, essentially defenseless host
• New tomato diseases emerged and threatened production
• Subsequent movement of tomato seed and plants spread some of these new tomato pathogen to new areas
• Some pathogens (mostly viruses) were spread with their insect vectors (e.g., thrips and whiteflies)
Tomato is a cosmopolitan crop attacked by a wide range of pathogens

BV: Begomoviruses
CTV: Curly top viruses
TSWV: Tomato spotted wilt virus
LB: Late Blight
EB: Early Blight
BS: Bacterial Spot
FW: Fusarium Wilt
PM: Powdery Mildew
TV: Torradoviruses
Diseases and their pathogens are not static

- Diseases and their causal agents change in terms of their relative importance and distribution
- Emerging diseases: new or previously known diseases that have become more of a problem, often due to a change in some aspect of the pathogen, pathogen vector, host and/or environment
- Phenomenon of emerging diseases is common to animals, human and plants
- HIV-AIDs, SARS, cholera, tuberculosis, influenza, drug-resistant *E. coli*, etc.
Emerging diseases of tomato

• ‘New’ diseases/pathogens
  - Tomato yellow leaf curl (TYLC) and other diseases caused by whitefly-transmitted begomoviruses
  - Thrips-transmitted tospoviruses (e.g., Groundnut ringspot virus, Capsicum chlorosis virus)
  - Torradoviruses (insect)
  - Pepino mosaic (seed/mechanical)
  - Viroids (seed/mechanical)
  - Powdery mildew
    (Oidium neolycopersici)
Emerging viruses: Geminiviruses

- A family of plant viruses (Geminiviridae) characterized by having:
  - twinned icosahedral virions
  - genome composed of one (monopartite) or two bipartite circular single-stranded (ss) DNA genome
  - transmitted by whiteflies (Bemisia tabaci) or leafhoppers
- Largest family of plant viruses (>200 species)
- Cause economically important diseases in a wide range of crop plants
- Many members are considered emerging viruses
Geminiviruses are a diverse group of viruses: Four genera are recognized based on genome structure, insect vector and host plants.

<table>
<thead>
<tr>
<th>Genome</th>
<th>Mastrevirus</th>
<th>Topocuvirus</th>
<th>Curtovirus</th>
<th>Begomovirus</th>
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<tbody>
<tr>
<td>Vector</td>
<td>Leafhopper</td>
<td>Treehopper</td>
<td>Leafhopper</td>
<td>Whitefly</td>
</tr>
<tr>
<td>Host</td>
<td>Monocots</td>
<td>Dicots</td>
<td>Dicots</td>
<td>Dicots</td>
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</tbody>
</table>
Begomoviruses

- Whitefly (*Bemisia tabaci*)-transmitted geminiviruses
- Recently (last 20-25 years) emerged as one of the largest and most economically important groups of plant viruses (>130 species)
- Cause severe diseases in many dicotyledonous crop plants (e.g., beans, cassava, cotton, cucurbits, pepper, tomato) in tropical and subtropical regions of the world
- Resistance not available in many crops
Local or parallel evolution drives emergence of a diversity of crop-infecting begomoviruses

Whiteflies feed on weeds infected with indigenous begomoviruses

Viruliferous whiteflies move to crop plants and introduce indigenous begomoviruses

Adaptation of the indigenous begomovirus and the emergence of a new crop-infecting begomovirus, which typically causes severe disease symptoms
Tomato begomoviruses

• >60 different begomoviruses infect tomato worldwide
• All are transmitted by *Bemisia tabaci*
• Not seed- or mechanically transmitted
• Have relatively narrow host ranges within the Solanaceae (tomato family)
• Cause similar symptoms including leaf curl, crumple, and yellowing; stunted and distorted growth; and can cause considerable yield losses
• One of the most important is *Tomato yellow leaf curl virus* (TYLCV), an emerging virus introduced in to the New World from the Old World (Middle East)
Emergence of new begomovirus species infecting tomato in West Africa

- Begomoviruses have emerged as a major constraint on tomato production in West Africa
- Molecular characterization has revealed a complex of at least 5 locally evolved monopartite begomoviruses and one or more betasatellites causing symptoms of leaf curl, yellow leaf crumple and a severe symptom phenotype
Worldwide Emergence of Tomato-infecting Begomoviruses

New World
Bipartite
Begomoviruses

Old World
Monopartite
Begomoviruses ± betasatellite
Emerging Viruses: Torradoviruses

- New virus-like diseases appeared in Europe (Spain), Mexico (Sinaloa) and Guatemala beginning ~2005
- Symptoms included necrosis of leaves and stems, and necrotic rings on green fruits
- Symptoms were initially confused with tomato spotted wilt
- Caused by members of new type of RNA virus: Torradovirus (Tomato torrado virus, Tomato apex necrosis/Tomato marchitez virus and Tomato chocolate spot virus)
- Vector appears to be whiteflies
- Resistance has been identified in some processing tomato cultivars
Emerging viruses:
Tomato necrotic spot virus

- Unusual virus-like symptoms appeared in processing tomatoes in California beginning in 2007
- Light brown necrotic spots and streaks on leaves and stems
- Similar to symptoms of torradoviruses and Tomato spotted wilt virus but tests were negative
- Confirmed as a virus by transmission studies
- Identified as a new ilarvirus and named Tomato necrotic spot virus
Tomato necrotic spot virus: An emerging virus not causing economic losses

• Disease incidence has been low and sporadic, often at edges of the field
• Transmission to tomato mediated by thrips feeding on leaves having infected pollen
• Emergence associated with increased thrips populations
• Primary host is unknown
• Rapid diagnostic test developed
• The ilarvirus *Parietaria mottle virus* is economically important in tomatoes in southern Europe
Emerging diseases of tomato

• ‘Old’ or reemerging diseases (pathogens)
  - Late blight (*Phytophthora infestans*)
  - Fusarium wilt (*Fusarium oxysporum f.sp. lycopersici*)
  - Bacterial speck (*Pseudomonas syringae pv. tomato*)
  - Bacterial canker (*Clavibacter michiganensis subsp. michiganensis*)
  - Tomato spotted wilt (*Tomato spotted wilt virus*)

• ‘Reemergence’ due to multiple factors
  - Changes (mutations) in the pathogen
    including resistance-breaking isolates/strains
  - Changes in cultural practices (grafting)
  - Changes in populations of an insect vector

• Red Queen’s hypothesis
  - Pathogens and hosts are in a constant evolutionary arms race where changes in the host are countered by changed in the pathogen
Emergence of a new form of a known disease: Fusarium wilt

- Initial symptoms are yellowing and wilting, followed by stunted growth and reduced yields
- Vascular tissue shows browning
- Caused by the fungus *Fusarium oxysporum f. sp. lycopersici*
- Seed and soil-borne
- Persists in soil indefinitely as resistant spores
- Effectively managed with resistant varieties
Fusarium wilt of tomato

- Fusarium wilt symptoms began showing up in resistant tomato varieties (to the known races 1 and 2) in late 1980-mid 1990s
- Isolations and pathogenicity tests confirmed *Fusarium oxysporum* f. sp. *lycopersici* and revealed the appearance of a new race (race 3)
- Race 3 has appeared in the Dominican Republic, Mexico and the US (California)
- A source of resistance was identified in the wild species *L. pennelli* (LA 716) and resistant varieties are now available
Emergence of a new form of a known disease: Bacterial speck of tomato

- Bacterial speck is a **leaf spot disease** caused by *Pseudomonas syringae pv. tomato* (Pst)
- Can be **economically important** in California in years with cool wet spring conditions
- Effectively **managed with resistant varieties** (containing the *Pto* gene)
- Speck-like symptoms **began appearing in resistant tomato varieties** ~10 years ago
- Due to the appearance of a **new race of Pst** (race 1) that is not recognized by the Pto gene
Effective disease management can be accomplished using an integrated pest management (IPM) approach.

Involves a combination of multiple management strategies (e.g., biological, chemical, cultural, genetic and physical) selected based on knowledge of the biology of the prevalent pathogen(s) in an area.

Goal is efficient management with minimal inputs of pesticide; economically and environmentally friendly.

An IPM program involved three basic steps:
1. Correct pathogen ID
2. Understanding pathogen biology/disease epidemiology
3. Development and evaluation of the IPM strategy

How can tomato growers fight back?
Awareness that a problem exists: regular field visits by trained personnel
Proper identification of a problem involves the knowledge and utilization of available resources
Human resources
- Professional crop consultants (private)
- Extension and University personnel (public/government/academic)
Reference materials
- Field guides, disease compendia etc.
- On-line resources
- International Plant Diagnostic Network (USAID IPM-CRSP)
The California Model

Growers contract **professional crop consultants (PCAs)**

- **University of California Cooperative Extension**
- **County-based Farm Advisors**
- **Grower organizations:**
  - **California Tomato Research Institute (CTRI)**
- **Private companies** e.g., seed companies

**On-line resources**

- **Thrips degree day model**

**Printed materials**

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*University of California *

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Rapid, Sensitive and Specific Diagnostic Tests have Improved Pathogen Detection

- **Lateral flow devices (immunostrips)**
  - Rapid and precise
  - Easy to use
  - Detection in the field
  - No equipment needed
  - TSWV, CMV, TMV, PVY, PepMV

- **PCR and sequencing**
  - Precise and sensitive
  - Laboratory-based test
  - More time-consuming
  - Available for most pathogens
PCR-Based ID of Plant Pathogens: Specific Amplification of a DNA Fragment of the Pathogen Genetic Material of (DNA or RNA)
Is there a PCR product, is it the right size and what is the sequence most similar to?

Real-time PCR is a newer approach that follows the amplification of the target fragment in real-time, via the monitoring of the incorporation of a dsDNA binding dye or activation of the fluorescent marker during the reaction, and allows for quantification of the PCR product.
Understanding the biology of the pathogen and epidemiology of the disease is necessary for developing and IPM program

• Where does it come from (sources of inoculum)?
  - seed
  - soil
  - weeds/other reservoir hosts
  - insects
• How and when does it infect the plant
• What is the host range
• How does it survive in the absence of the host (reservoir hosts, crop debris, soil, etc.) and for how long
• If it is a known pathogen, much of this information may be available, whereas if it is new then research may be needed to answer some of these questions
Develop an IPM program

- Select appropriate management strategies based on knowledge of the biology of the pathogen
  - regulatory (do not introduce exotic pathogens on/in seeds and transplants)
  - avoidance (field location, planting dates)
  - disease resistance (conventional and transgenic)
  - pathogen-free propagative materials (seeds and transplants)
  - protection (screenhouses, greenhouses, row covers)
  - disease monitoring and forecasting
  - vector management (insecticides)
  - pesticides (fungicides, bactericides, etc.)
  - removal of diseased plants (roguing)
  - sanitation (destroy harvested crops, weeds, volunteers)
  - crop rotation
  - host-free periods
Development of an IPM program for *Tomato yellow leaf curl virus* in the Dominican Republic

- In the early 1990’s a **new disease of tomato** appeared in the Dominican Republic (DO)
- The disease **looked like TYLC** (stunted, erect plants with small upcurled leaves with interveinal yellowing and crumpling)
- The disease **spread quickly** by high populations of indigenous *Bemisia tabaci* and caused **heavy losses** on the highly susceptible varieties grown in the DO
- Molecular tools (PCR and sequencing) established that it was *Tomato yellow leaf curl virus* (TYLCV)
- TYLCV was inadvertently been introduced to the DO and threatened to destroy the processing tomato industry
Investigation into the biology of TYLCV in the DO led to establishment of a host-free period for TYLCV

- **Molecular tests** revealed that TYLCV was primarily infecting tomato and not other crops and weeds
- **Recommendation** was made to implement a tomato-free period in the main growing areas of the North and South to break the disease cycle of the virus
- **The government** implemented a mandatory 3 month whitefly host-free period to because of the importance of the tomato industry and the damage to other crops by whiteflies
Biological properties that make a host-free period effective for management of TYLCV (and other begomoviruses)

- Not seed-transmitted
- Narrow host range
- Whiteflies have relatively short (~30 day) life cycles and are not transovarially transmitted
- Many economically important diseases caused by begomoviruses are in annual crops (cotton, cucurbit, peppers and tomatoes)
- Thus, a 2-3 month host-free period can be a very effective and sustainable management strategy for begomoviruses and can also reduce whitefly populations
Host free period is a key component of the IPM strategy For TYLCV in the DO

- The host-free period was implemented along with a number of other practices (vector control [esp. in transplants], planting early maturing/resistant varieties), and sanitation
- Evidence that the host-free period was effective:
  - 4-8 week delay in the appearance of TYLCV symptoms following the host-free period
  - Dramatic drop in detection of TYLCV in whiteflies during the host-free period
- This IPM approach has been used for ~20 years and has allowed for the recovery of the industry
The host-free period stimulated research that revealed other aspects of the biology of TYLCV in the DO

- TYLCV persists during the host-free period in symptomless weeds
- This is consistent with an ‘edge-effect’ for the initial appearance of TYLCV in the field
- Pepper is a poor host of TYLCV, but will develop symptoms under high virus pressure
- Common bean is also a TYLCV host, especially large-seeded Andean types
- Certain TYLCV-resistant tomato varieties sustain high virus titers despite not showing symptoms
- These findings have helped fine-tune or maintain aspects of the host free period
IPM program for TYLCV in The Dominican Republic

- Three-month whitefly host-free period (June-August)
- Government-enforced
- Plant early maturing hybrids at the start of the season (Sept-October) and resistant varieties later (Nov-Dec)
- Systemic insecticides (e.g., neonicotinoids) at planting and (if needed) contact insecticides during the growing season
- Extensive sanitation following harvest
- Monitoring for violators during the host-free period
- Tomato production in the DO is greater now than before the introduction of TYLCV
Development of an IPM program for *Tomato spotted wilt virus* in the Central Valley of California

- In 2005, an outbreak of *Tomato spotted wilt virus* (TSWV) caused substantial economic losses in the Central Valley.
- Virus involved was identified and characterized based on symptoms and diagnostic tests (immunostrips and PCR/sequencing).
- Disease outbreaks were associated with high populations of thrips.
- Traditionally, TSWV has been a disease of minor importance in processing tomatoes in California.
TSWV Biology-General

- Not transmitted on or in seed
- Not transmitted by touch
- Very wide host range
- Virus overseasons in weeds, ornamental and bridge hosts
- Introduced into and spread within crops by thrips
- Plants in older fields can serve as inoculum sources for newly planted fields
- Thrips must acquire the virus as immatures to transmit as an adult; not transmitted through eggs
TSWV Biology: California Central Valley

- A research project was initiated by CTRI to investigate factors involved in the outbreak and to develop management strategies
- No evidence of a new type or strain of TSWV
- Transplants generally free of TSWV and thrips
- Weeds are not extensively infected with TSWV
  - Exception: fallow spring lettuce fields with high weeds populations
- A number of TSWV bridge crops were identified including fava bean, lettuce and radicchio
- Almonds are not sources of thrips or TSWV
- Alfalfa, onions and wheat are not hosts of TSWV but are sources of thrips
- Thrips do not have high levels of TSWV until mid- to late in the growing season (July-October)
### Development of TSWV in Processing Tomato Fields

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<thead>
<tr>
<th></th>
<th>Winter</th>
<th>Early-Mid Season</th>
<th>Late Season</th>
<th>Off Season</th>
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</thead>
<tbody>
<tr>
<td>TSWV</td>
<td>TSWV overwinters at low levels in weeds, bridge crops and thrips (?)</td>
<td>Infections with TSWV –low incidences, depending on populations of virus carrying thrips</td>
<td>Potential for higher incidence/epidemics and economic losses in late-planted crops. Late infections may be limited to some shoots</td>
<td>Persistence in weeds, reservoir hosts, bridge crops (i.e., radicchio, lettuce and fava beans)</td>
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<tr>
<td></td>
<td><strong>High</strong></td>
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<td><strong>Low</strong></td>
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**Amplification in susceptible crops (dependent on initial inoculum thrips populations)**

### Western Flower Thrips Population Dynamics in the Central Valley of California

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<tr>
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<th>Winter: Thrips overwinter at very low levels</th>
<th>Spring: Thrips populations increase</th>
<th>Summer: Peak populations</th>
<th>Fall: Populations decrease</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>High</strong></td>
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<tr>
<td><strong>Low</strong></td>
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**Target: 2nd and 3th Adult thrips Generations**  
**Increased Viruliferous thrips populations**
IPM for thrips and TSWV

- **Before planting**
  - Varietal selection
  - Use TSWV resistant varieties (with the Sw-5 gene) especially in hot-spot areas or late-planted fields
  - Use non-Sw-5 varieties that are less susceptible to TSWV
  - Plant TSWV- and thrips-free transplants
  - Field placement (avoid planting near potential bridge crops, established fields of TSWV-susceptible crops or in hot-spot areas
IPM for thrips and TSWV

• During the season
  - Monitor fields for thrips (yellow sticky cards) and TSWV (visual)
  - Manage thrips with insecticides at early stages of crop development when thrips populations begin to increase
  - Rotate insecticides to minimize development of insecticide resistance in thrips
  - Removal of TSWV-infected plants early (seedling infection) and when percent infection is low (<5%)
  - Weed control in and around fields
A degree-day model for predicting thrips population development

A brief interpretation of the current situation and advice about when to expect thrips activity, to help with scheduling insecticide sprays.

Weather widget, Showing live weather. Clicking will open the widget in full screen mode. Clicking on “NWS” in lower right will open the NWS web site.

Thrips population projection, showing expected dates for major developmental stages.
IPM for thrips and TSWV

- **After harvest**
  - Promptly remove and destroy plants after harvest
  - Avoid ‘bridge’ crops that are TSWV/thrips reservoirs and overlap with tomato/pepper (e.g., radicchio, lettuce, fava bean)
  - Control weeds/volunteers in fallow fields, non-cropped, or idle land near next year’s tomato fields
The IPM program developed for thrips and TSWV in processing tomatoes in California has been summarized in a flyer and presented in growers meetings and other venues.
Conclusions

- Processing tomatoes will continue to face diseases with the potential to cause substantial yield loss.
- The nature and relative importance of diseases will always be changing with the implementation of new disease management strategies and the emergence/re-emergence of new/known pathogens (Red Queen hypothesis).
- New detection technologies, better understanding of pathogen biology and improved management strategies allow growers unprecedented opportunities to reduce losses due to diseases and minimize use of pesticides (best agricultural practices).
- Delivering information, particularly in developing production areas, is critical and can be challenging.
- IPM approaches should be developed and implemented; reliance on any single strategy should be avoided.
Thank you for your attention!

Any questions?