

**Biology of *Tomato spotted wilt virus* (TSWV)
and Other Viruses that Affect Peppers**

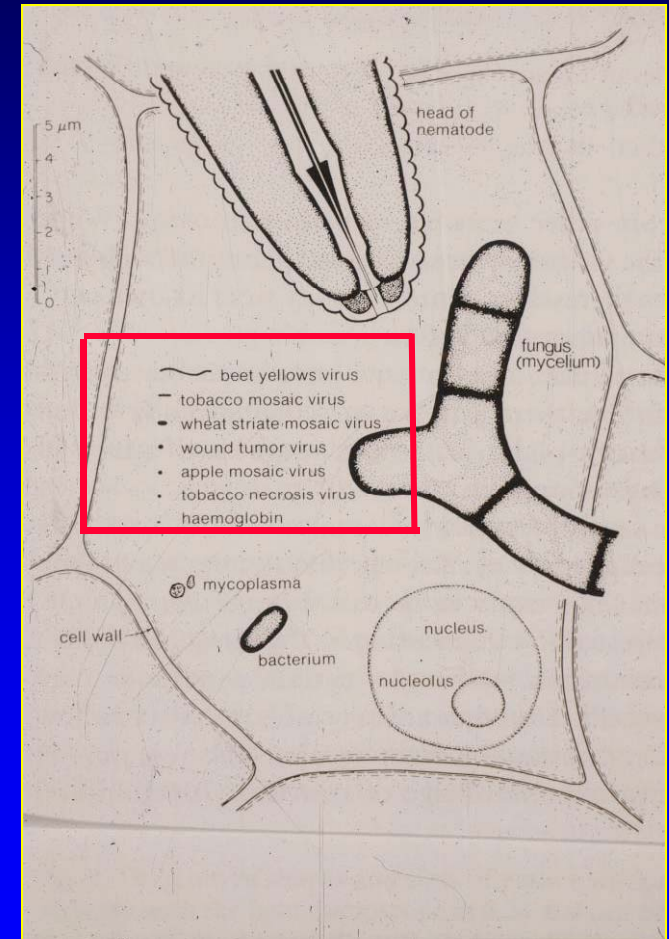


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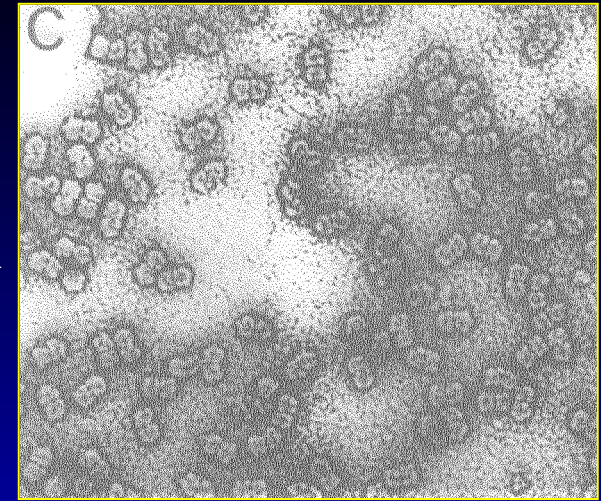
Diseases of plants are caused by biotic and abiotic factors

- Causal agents of disease can be broadly classified as **biotic** (e.g., fungi, **viruses**, bacteria, phytoplasmas and nematodes) and **abiotic** (air pollution, herbicide damage and excesses and deficiencies in water and nutrition)
- Plants respond to these agents with **disease symptoms**
- **Diagnosis of the cause of symptoms can be very difficult**



Plant Viruses

- **Parasitic genetic elements** (RNA or DNA) covered by a protective protein shell →
- **Most important pathogen of animals** (HIV, influenza); **second most important pathogen of plants**
- **Viruses take over the cellular machinery** of the plant and spread throughout the infected plant
- This results in the **development of various types of disease symptoms** →
- **Plant-to-plant spread** of viruses most commonly occurs via **insects** (also via seed, nematodes, etc.)
- Plant viruses are very **difficult to diagnose and control**



Plant virus particles (virions)



Plant virus symptoms

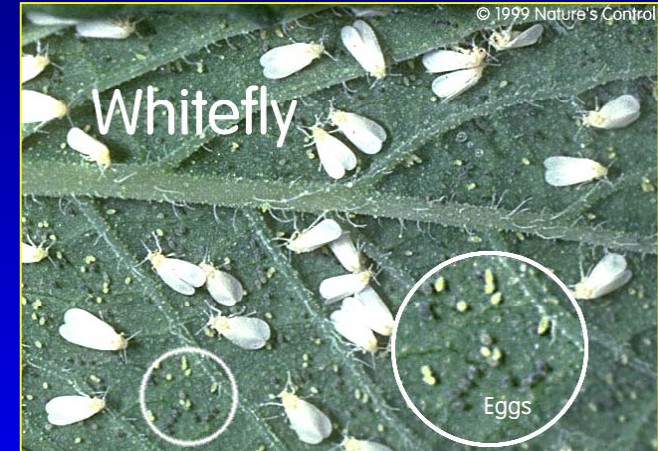
Symptoms of virus infection

- symptoms vary considerably depending on the virus/host combination-can be **local or systemic**
- most common symptom is **stunted growth**
- most conspicuous symptoms is **mosaic or mottling** of leaves
- other symptoms include **necrosis, ringspot, yellowing and etching**
- **abnormalities in growth or form** such as distorted growth, curling, crumpling, shoestrings, enations



Plant-to-plant spread of viruses

- **Plants are not mobile** so, unlike many animals viruses that can rely on host movement and contact, **plants viruses have had to evolve a means to move from an infected to an uninfected plant**
- In nature, this is most commonly achieved by **arthropod (insect) vectors**, such as **aphids, leafhoppers, whiteflies, thrips and beetles**.
- Other vectors include **mites, fungi nematodes and even humans and animals**
- Viruses can also be spread via **pollen, seed or vegetatively**



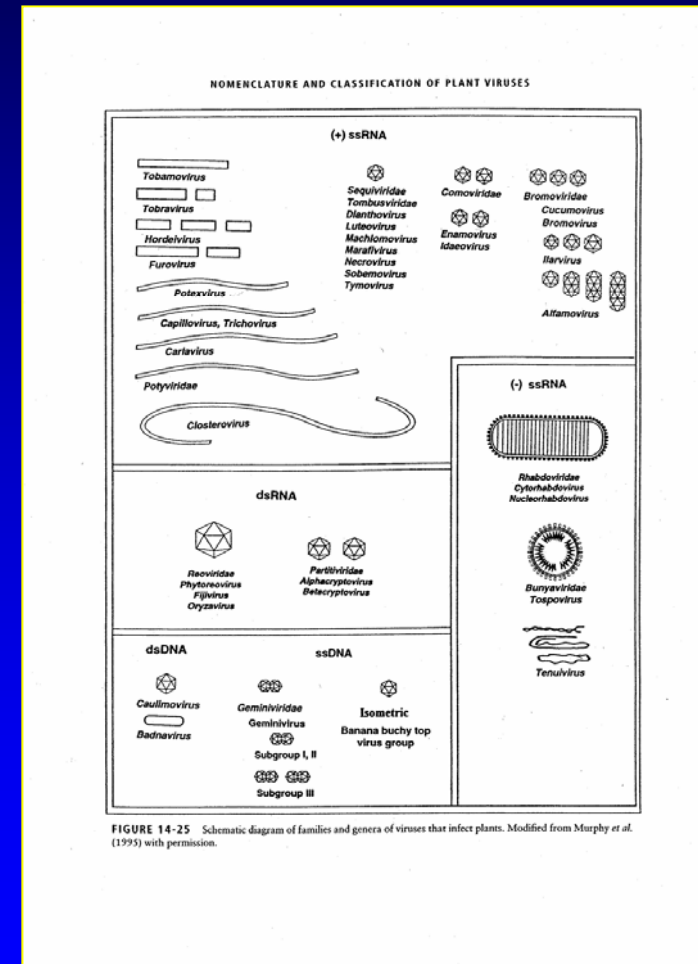
Thrips-Larva



Thrips-Adult

Pepper-infecting viruses

- **~70 viruses** known to infect peppers worldwide
- **~10 of these known to occur in California**
- **Most are not seed-transmitted**
- **Difficult to identify based on symptoms**
- **Mixed infections are common**
- **Transmitted from plant-to-plant by various insects, primarily aphids and thrips**
- **Best managed by an IPM approach**



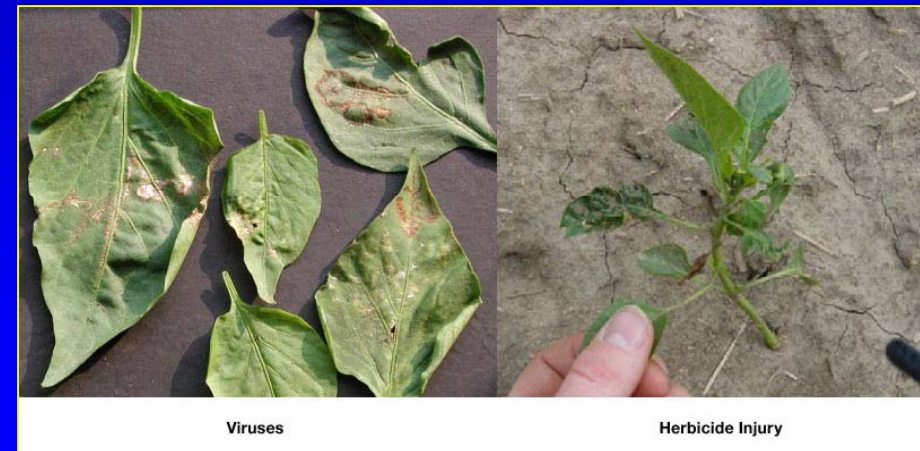
Integrated Pest Management (IPM) of Plant Viruses

- An approach that **combines multiple management strategies** (e.g., biological, cultural, genetic and chemical) selected based on **knowledge of the biology of the virus(es)**
- Goal is **efficient management with minimal inputs of pesticide; economically and environmentally friendly**
- Three basic steps:
 1. **Correct pathogen ID**
 2. **Understanding pathogen biology/ disease epidemiology**
 3. **Development and evaluation of a management strategy**



Diagnosis of plant virus diseases

- **Very difficult based upon symptoms alone**
- **Indicator plants can be used for sap-transmissible viruses**
- **New modern approaches are the most definitive**
 - **Serological**
 - Enzyme-linked immunosorbent assay (ELISA)
 - Immunostrips
 - **Nucleic acid-based**
 - DNA probes
 - Polymerase chain reaction (PCR) and DNA sequencing



ELISA

- **Laboratory test that requires an antibody to the virus being tested for and some equipment**
- **Relatively expensive and requires trained personnel**
- **Virus-infected samples appear are yellow**
- **Best method for many RNA viruses (e.g., CMV, PVY, TMV, etc.)**



Immunostrips for detection of *Tomato spotted wilt virus*, *Cucumber mosaic virus*, and *Tobacco mosaic virus* and *Potato virus Y*

- Rapid and precise
- Easy to use
- Detection in the field
- No equipment needed
- Not as sensitive
- Relatively expensive

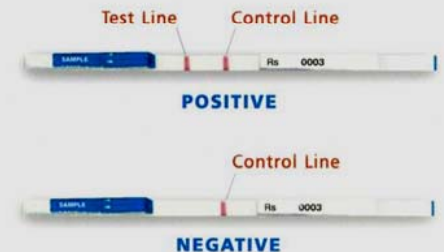
Agdia ImmunoStrips™ make testing simple and reliable.

Agdia's ImmunoStrips™ are user-friendly and provide a reliable and economical way to test plants.



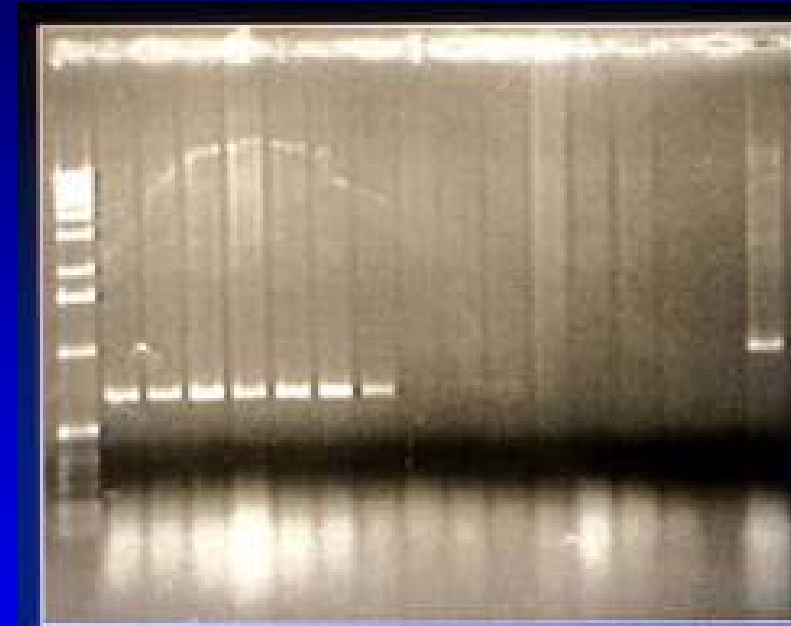
How to read ImmunoStrips™

The control line on our ImmunoStrips™ assures that the test is working properly. If the control line does not appear, the test is invalid. If the sample is positive, a red to purple test line will appear similar to that of the control line. If the sample is negative, the test line will not appear.



PCR

- Laboratory test that **amplifies small amounts of viral genetic material**
- Requires **'primers'** or small virus-specific-sequences to initiate the reaction
- Requires **equipment and lab facilities**
- Relatively **expensive and requires trained personnel**
- Positive result is the **presence of a virus-specific DNA fragments**
- **Best method for DNA viruses** (geminiviruses) and some RNA viruses



PCR detection of SLCV in squash

Understanding the biology of the virus is necessary for effective disease management

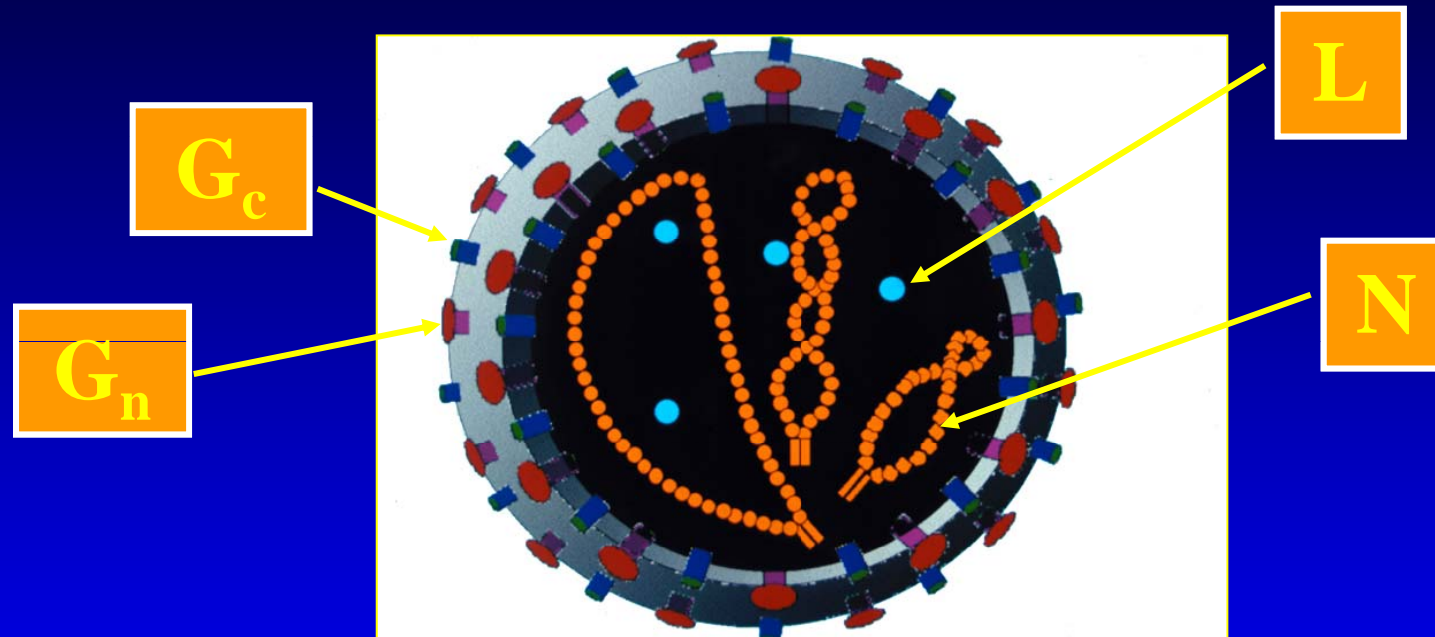
- **Properties of the virus** (virion structure and genetic material)
- **Host range**
- **Vector** (insect or other)
- **Sources of inoculum**
 - seed
 - weeds/other reservoir hosts
 - old crops
 - insects
- **Means of survival in the absence of the economic hosts**

Key viruses affecting peppers in CA production areas

• <i>Alfalfa mosaic virus</i> (AMV)	Alfamovirus		Aphid
• <i>Cucumber mosaic virus</i> (CMV)	Cucumovirus		
• <i>Pepper mottle virus</i> (PepMoV)	Potyvirus		
• <i>Potato virus Y</i> (PVY)	Potyvirus		
• <i>Tobacco etch virus</i> (TEV)	Potyvirus		
• <i>Pepper mild mottle virus</i> (PMMV)	Tobamovirus		Seed & Mechanical
• <i>Tobacco mosaic virus</i> (TMV)	Tobamovirus		
• <i>Tomato mosaic virus</i> (ToMV)	Tobamovirus		
• <i>Tomato spotted wilt virus</i> (TSWV)	Tospovirus	→	Thrips
• <i>Beet curly top virus</i> (BCTV)	Curtovirus	→	Leafhopper

*Whitefly-transmitted geminiviruses are not present in CA

Tomato spotted wilt virus (TSWV)
Tospovirus



FAMILY *Bunyaviridae*

Genus *Tospovirus*: the only plant infecting genus

TSWV Susceptible Crops/Ornamentals

Beans
Celery
Cole crops
Eggplant
Fennel
Gerbera
Lettuce
Oregano
Peas
Pepper
Petunia
Radicchio
Sages
Spinach
Sunflower
Tomato



**TSWV is most widely spread
and has an
extremely wide host range
(over 1000 species)**

TSWV Susceptible Weeds

Barnyard grass
Black nightshade
Bindweed
Bur clover
Common sunflower
Dodder
Fiddle neck
Ground cherry
Groundsel
Jimsonweed
Lambs quarters
Malva
Mustard
Nettle
Pigweed
Prickly lettuce
Purslane
Russian thistle
Sowthistle
Tree tobacco

Tomato spotted wilt virus (TSWV):

A pepper virus with a very wide host range



- **Very common worldwide and incidence in California has increased over past 5-10 years.**
- **All stages of plant growth are affected. The severity of symptoms depends on time of infection, the variety grown and environmental conditions.**
- **Thrips are the only means of transmission.**
- **Not seed or mechanically transmitted.**
- **Resistance to TSWV is available and is a single dominant gene (*Tsw*).**
- **Can be broken at high temperatures and age - dependent.**



Tomato spotted wilt virus (TSWV): symptoms



- Plants infected while they are young display **severe stunting, yellowing or chlorotic flecking of the whole plant, necrosis on leaves and very little yield.**
- Foliar symptoms include **yellow or necrotic concentric ring patterns, and mosaic with chlorotic and necrotic spots.**
- Fruit of infected plants may show **necrotic spots and streaks, mosaic, and ring patterns.** On ripe fruit, yellow spots with concentric rings or necrotic streaks.

TRANSMISSION



Egg

ACQUISITION BY LARVAE IS CRUCIAL



1st instar

2nd instar

Tospovirus Transmission Cycle

VIRUS PASSAGE



VIRUS PASSAGE



Pupal Stages Do Not Feed

Only adults that acquire as larvae can transmit.

(Whitfield et.al., 2005)

Photos by J.K. Clark

Biology of thrips/TSWV in the Central Valley

- **Low populations of thrips persist overwinter** and in association with weeds and winter (bridge) crops
- **TSWV does not seem to overwinter well in weeds or other winter crops** (almonds, onion and wheat), **but it can be present in bridge crops** such as fava bean, lettuce and radicchio, and high populations of **weeds in fallow fields**
- **During the growing season, TSWV builds-up in susceptible crops**, mostly tomato and peppers; **thrips increase on many hosts**, including alfalfa, onion, wheat.

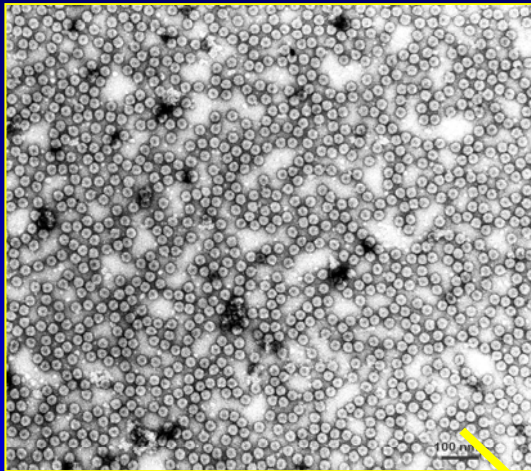
Complex of aphid-transmitted pepper viruses

- Cause **mosaic diseases** of peppers (sweet and hot peppers) that can cause economic losses in the Central Coast production areas
- **Symptoms** include stunted growth, leaf curling and crumpling and some degree of mosaic and mottling of leaves; fruit will show discoloration and bumpiness
- At least **five different viruses** (*Cucumber mosaic virus* [**CMV**], *Alfalfa mosaic virus* [**AMV**], *Pepper mottle virus* [**PepMoV**], *Potato virus Y* (**PVY**) and *Tobacco etch virus* [**TEV**]) **may be involved**.
- It is **very difficult to identify which virus(es) are causing the symptoms based upon disease symptoms alone**

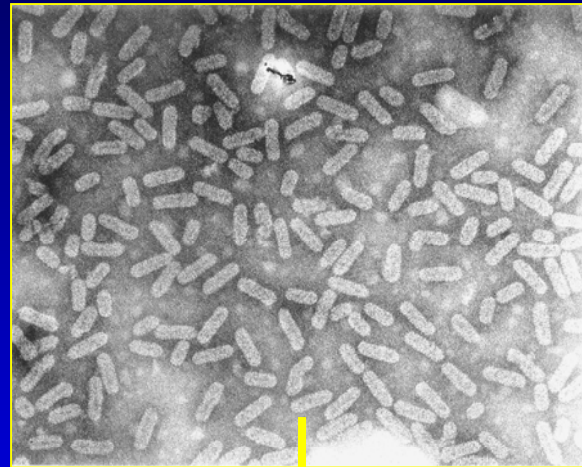


Aphid-transmitted virus complex-virion types and vectors

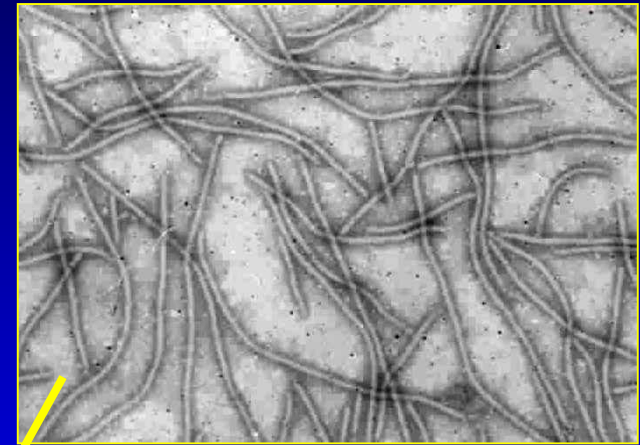
CMV
-icosahedral



AMV
- bacilliform particles



PepMoV/PVY/TEV
-flexuous rods



-aphids



Cucumber mosaic virus (CMV):

A pepper virus with a with a wide host range

- Spherical RNA virus
- Very common worldwide and in California
- Has a **very wide host range (1200 species)** including crops (common bean, cowpea, melons, peppers and tomatoes), ornamentals and weeds

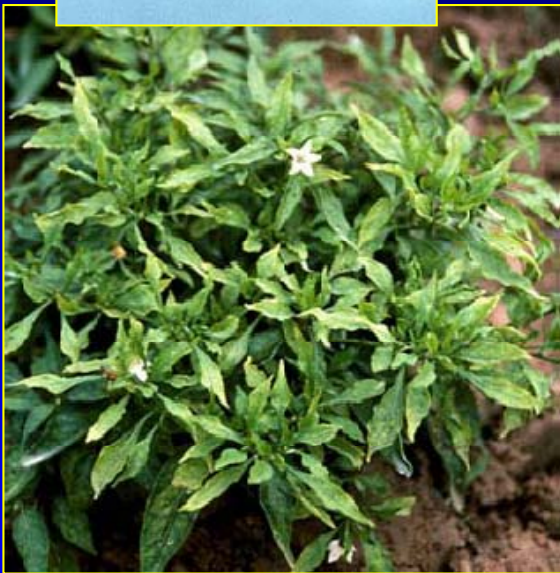
- **Symptoms** include leaf curling, mosaic, and oak leaf patterns, stunted and distorted growth and fruit may be malformed and have conspicuous concentric rings or spots
- **Seed transmission in peppers recently reported**
- Transmitted from plant-to-plant by **various aphid species in a non-persistent manner** (acquired and transmitted in seconds, retained for hours)



Cucumber mosaic virus (CMV)

- Symptoms vary widely. One of the most common symptom is a **severely stunted, nonproductive plant that has dull light green foliage with a leathery appearance but not distinctive foliar markings.**

- Plants generally show **stunting, leaf curling, mosaic, and oak leaf patterns.**
- **Fruit** may be **wrinkled, bumpy**, pale to yellowish green in color, sometimes with **sunken lesions**. On some varieties **lines or ring spots** may develop.
- **Dominant virus disease of pepper in Gilroy area**



Alfalfa mosaic virus (AMV)

- A distinctive bright-yellow mosaic develops on leaves.
- Often fruits are mottled and distorted
- Generally occurs when peppers are grown near alfalfa.
- Relatively common in CA but generally does not often cause significant yield loss.
- Pepper varieties **resistant** to AMV are **not available**





Pepper Mosaic Diseases Caused by Potyviruses *Pepper mottle virus (PepMoV)*

- In fields; plants may develop **systemic mottle, distortion** and may be **stunted**.
- In greenhouse; plants first develop **vein-clearing** followed by **chlorotic mottle** in newer leaves.
- Fruits **may be distorted, mottled and small**.
- Often occurs in pepper in **mixed infections with other potyviruses**.
- Resistant varieties are **available**.



Pepper Mosaic Diseases Caused by Potyviruses

Potato virus Y (PVY)



- **Plant stunting, systemic vein-clearing, leaf mosaic or mottling, and dark green vein-banding** of the leaves. **Necrosis in the veins and petioles** often develops.

- This may be followed by **stem necrosis** and **defoliation**, death of the top bud and **plant death**.

- Affected **fruit** may be **smaller, deformed**, and with a **mosaic** pattern.

- **Resistant varieties are available.**



Pepper Mosaic Diseases Caused by Potyviruses *Tobacco etch virus (TEV)*



- Affected pepper plants show foliar **mottling** or **mosaic** patterns, **leaf distortion**, and **stunting**. **Vein-clearing** and **vein-banding** symptoms also occur.
- **Plants** infected early have **small, misshapen fruit** and can be severely **stunted**.
- **Fruits** from such plants have **severe mosaic** symptoms.
- Unlike sweet pepper, **infected hot pepper plants can show root necrosis, wilting and death**.
- **Resistant varieties are available.**

Mechanically Transmitted Tobamoviruses

Tobacco mosaic Virus (TMV), Tomato mosaic Virus (ToMV) and Pepper mild mottle virus (PMMV)



- TMV and ToMV are very closely related.
- TMV, **historically is a very severe disease** but now controlled primarily by the use of resistant varieties.
- Symptoms can include **necrosis** on any plant part, **defoliation**, and/or **mosaic** symptoms on **leaves, stems, and fruit**. Generally, infected plants have a **chlorotic mosaic** with **distortion** of younger leaves, and **stunting**.
- **PMMV in pepper also variable but generally mild. Infected as seedling remain stunted. Not in California yet but seed-borne and can be a problem.**

Beet curly top virus (BCTV)

- A disease caused by a group of related viruses vectored by the beet leafhoppers, known to infect a broad range of crop (sugarbeet, tomato, pepper, bean, spinach, and cucurbits) and weed hosts in many plant families.
- It is most commonly observed in Central Valley, although it may occur elsewhere.
- **Serious economic damage from this virus is unusual.**
- When seedlings are infected, **leaves** turn **yellow**, **twist and curl upward**, and **thicken** to become **stiff and crisp**. Petioles may curl downward. **Fruit set is reduced**. Fruit appear **dull** and **wrinkled**, and tend to **ripen prematurely**.



(*Circulifer tenellus*)



Thickened leaves curl upward

Biology of pepper-infecting viruses

- **Most of these viruses persist in weeds or volunteer crops**
- **Insect vectors (aphids and thrips) move the viruses out of weeds (many of which do not show obvious disease symptoms) into pepper and then spread the viruses within and between pepper crops**
- **Disease severity is often related to the insect vector population**
- **Aphid-transmitted viruses are more unpredictable and can impact peppers when aphid flights/populations are high**
- **For TMV/PMMV the most important means of survival between crops is in seed then spread within and between fields by workers on contaminated hands, clothing, and tools**
- **Because of the different biology of these viruses, proper ID is important in selection of management strategies**

Management of pepper-infecting viruses

- Management is difficult
- There are **no varieties that are resistant to all of these viruses**
- For PMMV, **virus-free seed should be used** and seed companies routinely test their seed using the antibody-based test ELISA
- More effective approaches have been **elimination of alternate hosts, timing of planting to avoid insect vectors and insecticide applications** to control vectors (aphids and thrips)
- There is some evidence that **new systemic insecticides (e. g., neonicotinoids) that effectively control aphids, and Dimethoate, Lannate, Radiant, and Mustang+Beleaf for thrips may help reduce the spread of these viruses**
- Resistant varieties for some of these viruses are available. Check with your extension agent for resistant cultivars that are available in your region

IPM for pepper-infecting viruses

- **Before the growing season**
 - Selection of **best varieties**
(high yielding, disease resistant)
 - Use **pathogen-free, high quality seed**
(tested free of PMMV)
 - Produce **pathogen- and insect-free transplants**
 - Maintain seedbeds away from cropped areas and from other susceptible plants
 - Treat seedlings with **neonicotinoids**
 - imidacloprid (Admire/Provado)**
 - thiamethoxam (Platinum/Actara)**
 - acetamiprid (Assail)**



IPM for pepper-infecting viruses

- **During the growing season**
 - **Plant healthy transplants**
 - **Do not plant near old established fields** Avoid 'hot spots'
 - **Monitor/manage insects vectors**
 - neonicotinoids
 - insect growth regulators (IGRs)
 - contact insecticides
 - **Reflective aluminum mulches**
 - **Roguing** plants with symptoms



IPM for pepper-infecting viruses

- **After the growing season**
 - **Sanitation**
 - remove and destroy old crops/volunteers regionally (plowing/physical removal)
 - **Weed management** (around fields)
 - **Avoid 'bridge' crops that can carry these viruses and overlap with tomato/pepper** (e.g., lettuce and radicchio)
 - **This should be done on a regional basis**

