Plant virus and virus like diseases

Tomato infecting viruses

Tomato virus diseases

- Tomato (*Solanum lycopersicum*) is by far the most important vegetable crop
  - In terms of economical value, tomato constitutes 72% of the value of fresh vegetables produced worldwide
- The number of described viral species that infect tomato crops amounts to **136**, whereas this number is notably lower for other vegetable crops with, For example,
  - 49 viruses that infect pepper (*Capsicum annuum*)
  - 53 that infect lettuce (*Lactuca sativa*)
  - 46 that infect melon (*Cucumis melo*)
  - 54 that infect potato (*S. tuberosum*)
  - 44 that infect eggplant (*S. melongena*).
  - Only for cucumber (*C. sativis*) have even more viral pathogens (**153**) been described (Brunt et al. 1996)
- The most common tomato viruses are:
  - **TYLCV; TSWV; CMV; TMV**

Emerging virus diseases

- Over recent years, several viral diseases, have emerged in greenhouse tomato crops and are presently impacting fresh-market tomato production in diverse geographic areas worldwide including :
  - *Tomato yellow leaf curl virus* (TYLCV; genus *Begomovirus*),
  - *Pepino mosaic virus* (PepMV; genus *Potexvirus*),
  - *Tomato torrado virus* (ToTV).

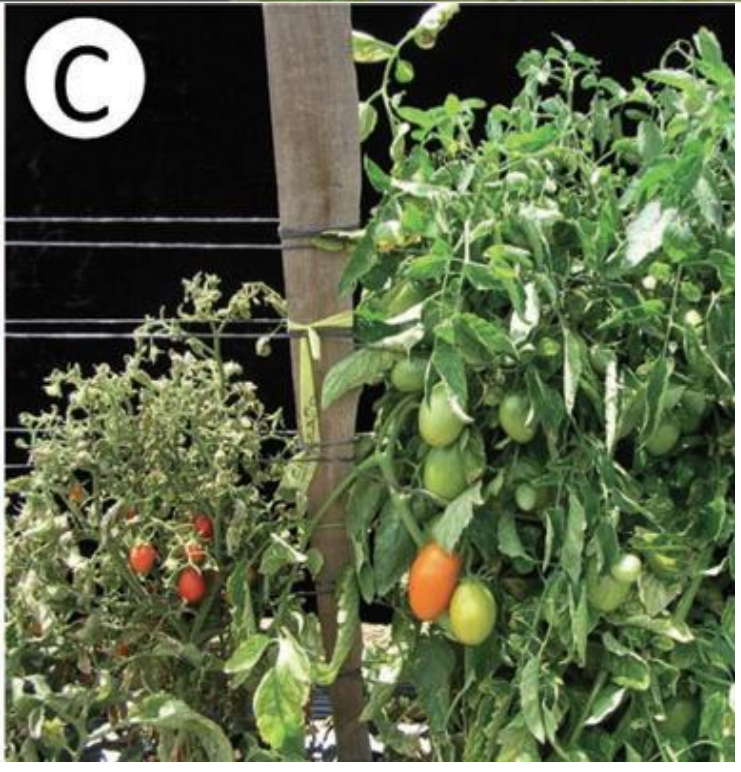
Fruit marbling induced by *Pepino mosaic virus;*

Tomato yellow leaf curle virus (TYLCV)

- TYLCV is a small DNA-containing virus with a double particle shape that identifies it as geminivirus.
- It is the **ONLY whitefly-transmitted geminivirus** that has a genome with only a single circular DNA component.
  - All other whitefly-transmitted geminiviruses have a two-component DNA genome.
- The greatest risk of TYLCV spread occurs when silverleaf whiteflies feed on and/or mature on TYLCV infected plants.
  - A silverleaf whitefly acquires the virus within 15-30 minutes, it then maintains the ability to transmit the virus for 10 days, but rarely much more.
  - Silverleaf whiteflies emerging from eggs are virus-free.
  - Virus acquisition is either by the larval or the adult stages of the insect.
- **Only silverleaf whitefly adults can transmit the virus**.
- TYLCV is not able to infect seed produced from an infected plant and it is not transmitted mechanically (Brown & Simone, 1994).

SYMPTOMS

- Infected plants have **extremely small leaves that curl upward, turn yellow around the margins, and are leathery**
- Plants with **short internodes that have developed a bushy, stunted appearance are easily seen in the field**.
- Infected plants exhibit **premature flower drop** and **loss of small fruit.**
  - Retained fruit are small, but not misshaped, unless a second virus is involved.
- The earlier a plant is infected the greater the subsequent yield loss
- Symptoms show approximately 15 days after viruliferous whitefly inoculation.



Tomato spotted wilt virus (TSWV)

- The first description of the '**spotted wilt**' disease of tomato occurred in 1915 in Australia (Brittlebank, 1915).
- The disease was later shown to be transmitted by thrips and caused by a (TSWV) (Samuel et al., 1930).
- The virus was soon reported in many other countries
- The more recent worldwide dispersal of Western flower thrips (*Frankliniella occidentalis*), the major vector of TSWV, led to **the re-emergence of TSWV as a major agricultural pest** in the 1980s with worldwide losses estimated to be in excess of **US$1 billion** annually by 1994 (Goldbach and Peters, 1994).

- The continuing economic importance of TSWV is due to:

  (i) its **worldwide distribution** and wide host range (>800 plant species), including tomato, pepper, lettuce, peanut and chrysanthemum;

  (ii) the **significant crop losses** resulting from infection;

  (iii) the **difficulty in managing the thrip vectors**, and hence the virus

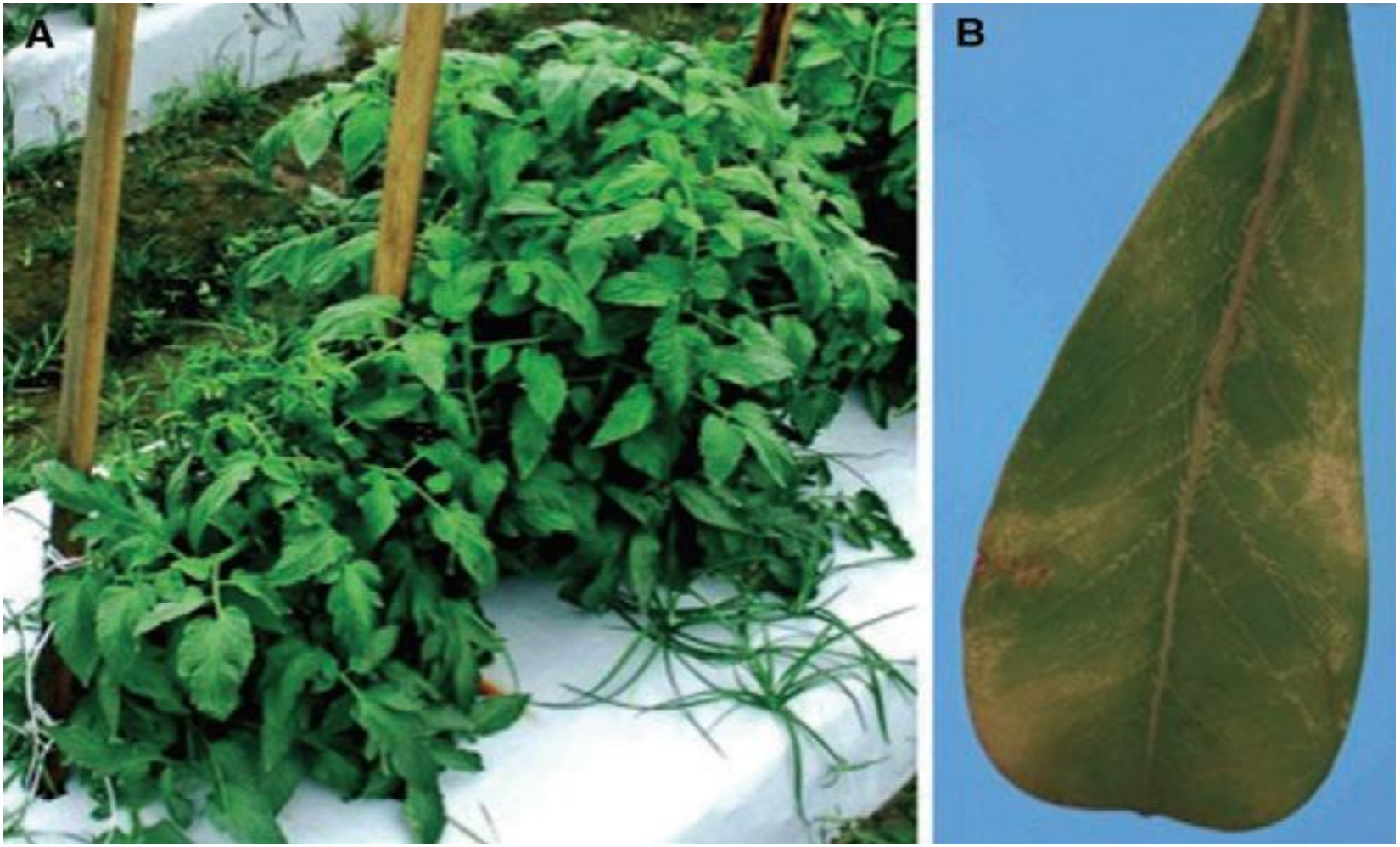
- Nearly a century after its first report, and following 30 years of intense molecular study, TSWV remains one of the 10 most economically destructive and scientifically challenging plant viruses

Symptoms

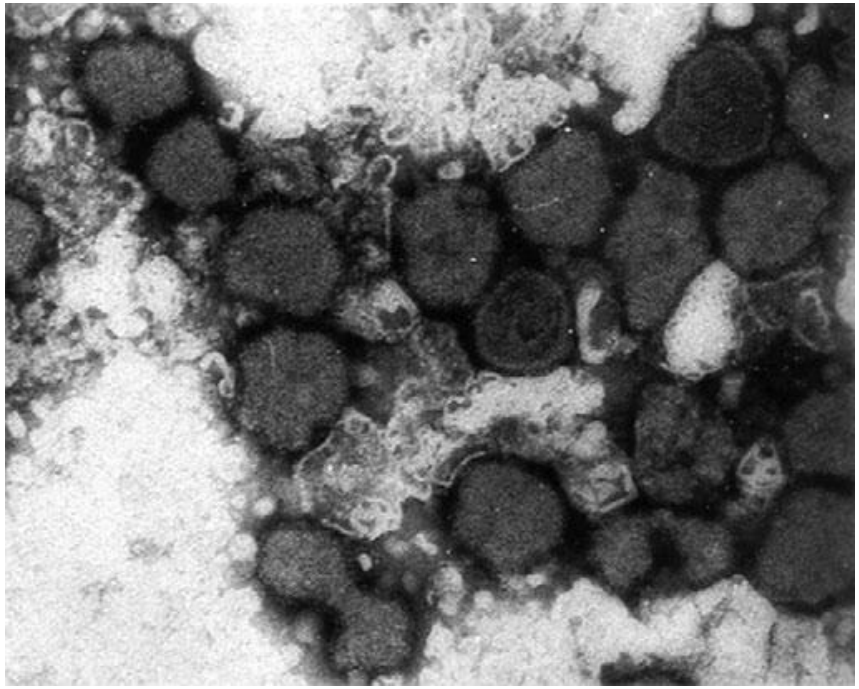
- TSWV causes variable symptoms, including **necrotic / chlorotic rings** and flecking on leaves, stems and fruits, with early infections leading to one-sided growth, drooping leaves reminiscent of vascular wilt, stunting or death.
- Later infections produce **unmarketable fruit** with striking chlorotic/necrotic ringspots that often appear only when the fruit reaches full color

Tomato spotted wilt virus (TSWV) symptoms.

(A) Stunted tomato plant (foreground) as a result of TSWV infection at an early stage of growth. Noninfected tomato plant (background) is shown for comparison.
(B) Ring/line patterns on desert rose (*Adenium obesum*) leaf from plant infected with TSWV.



- Subsequent molecular studies of TSWV supported the creation of the genus ***Tospovirus*** (named for TSWV, the type and only original member) within the family ***Bunyaviridae***
  - Later study and characterization of similar viruses, some of which had been classified previously as TSWV isolates, placed 20 species (accepted and tentative) in the genus ***Tospovirus*** today.



Tospoviruses are unique among plant viruses

- TSWV and more recently described tospoviruses are **unique among plant viruses** in that:
  - **Virions are enveloped** in a host-derived membrane studded with two viral glycoproteins ,
  - **Virions** contain one **negative-sense and two ambisense single-stranded RNAs**
  - Nucleic acids are encapsidated in **multiple copies of the viral nucleocapsid protein.**
- The **TSWV biology** are sufficiently novel to mention:

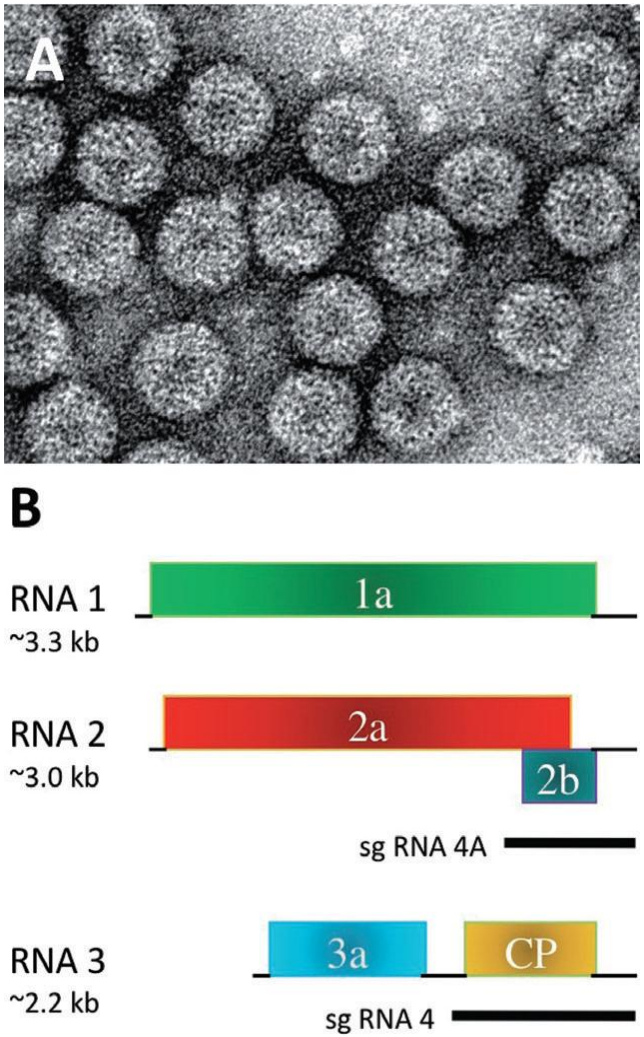
  (i) **Virions contain the viral RNA-dependent RNA polymerase** which uses host cell **mRNAs to prime** viral transcription via cap-snatching

  (ii) **Thrips can only transmit TSWV if acquired as larvae**, although both larvae and adults are able to transmit
- **TSWV replicates in its thrip vectors**, making thrips both vectors and mobile hosts for the virus,
  - suggesting that TSWV and other tospoviruses may have evolved from thrip-infecting species to thrip- and plant-infecting species.

Cucumber mosaic virus (CMV)

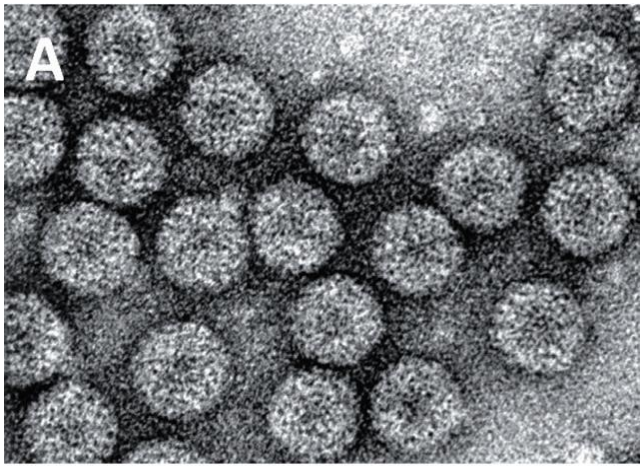
- The mosaic disease caused by CMV was first described in 1916 and, over the years, this virus has been found to infect many crop species.
- *Cucumber mosaic virus* (CMV) is the type member of the genus *Cucumovirus* in the family ***Bromoviridae***.
- CMV particles are icosahedral in shape and 29 nm in diameter , each consisting of 180 subunits of a single CP of ~24 kDa and one of the genomic RNAs.
- Based on their nucleic acid sequence similarity, CMV strains can be divided broadly into two major subgroups, designated (**I**) and (**II**), with subgroup I strains divided into two (**A**) and (B) or more additional subgroups.
- The CMV **genome contains five genes**, expressed from either the **three genomic RNAs** or **two subgenomic RNAs**

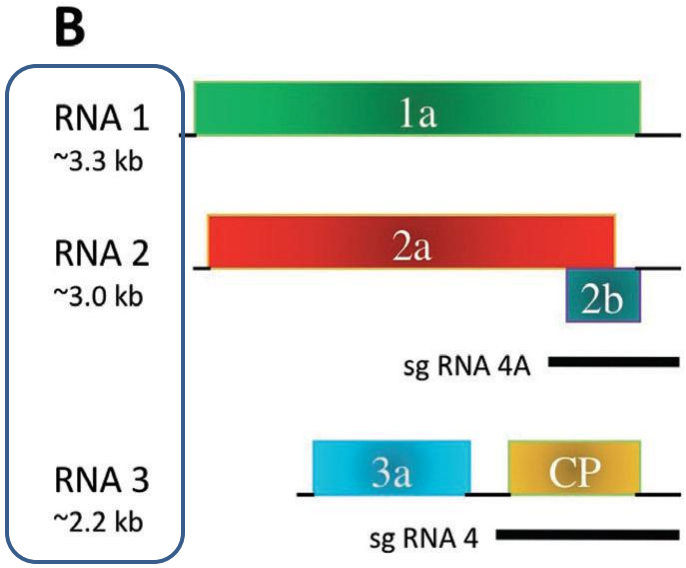
The CMV **genome contains five genes**



- The **1a** and **2a proteins** are involved in **virus replication**, which occurs on tonoplast membranes,
- **The 2b protein** is an **RNA silencing suppressor**, an antagonist of other host defense mechanisms and a viral recombination effector protein.
- **The 3a protein** and **CP** are essential for **both cell-to-cell and long-distance movement**, processes affected by all of the CMV-encoded proteins.

The CMV **genome contains five genes**

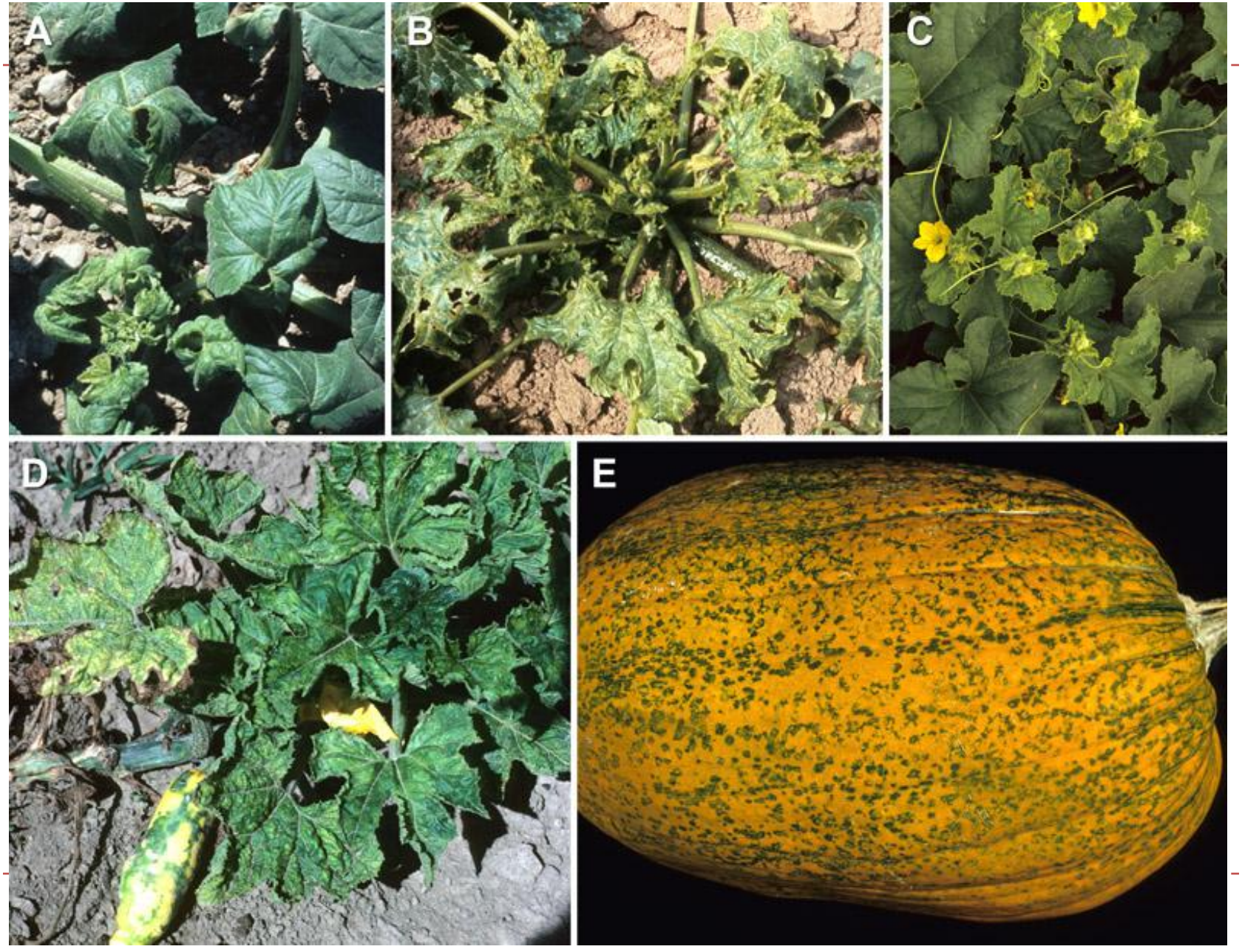




- Protein **2b and CP** are expressed from subgenomic RNAs, designated **RNA 4A** and **RNA 4**, respectively.
- **RNA 4 is packaged** together **with RNA 3**, whereas the packaging arrangements for **RNA 4A** are not known, except that it is only packaged by subgroup II CMV strains.
- **RNA 5**, which is also packaged only by subgroup II strains of CMV, corresponds to the 3′ nontranslated region of RNAs 2 and 3. Its function is not known.

- CMV has been studied extensively at the molecular level, even though the nature of various CMV–plant interactions is beginning to become clear.
- CMV also supports **satellite RNAs** of c. 330–390 nucleotides, some of which induce a **lethal necrosis in tomato,** with a few inducing **chlorosis** in tobacco, tomato or pepper, but most satellite RNAs **attenuate CMV-induced symptoms** on most hosts tested.
- CMV **interacts synergistically** with potyviruses, tobamoviruses and PVX in solanaceous plants, as well as with potyviruses in cucurbit hosts

Figure 3 A-E. CMV infection of cucurbits 3A. Severe epinasty in summer squash. 3B. Stunted and malformed leaves and fruit surface rugosity of zucchini. 3C. Stunted growing tips of muskmelon. 3D. Green blotches on yellow squash. 3E. Mosaic pattern on pumpkin fruit (Courtesy of T. A. Zitter)



Factors have contributed to the success of CMV as a pathogen

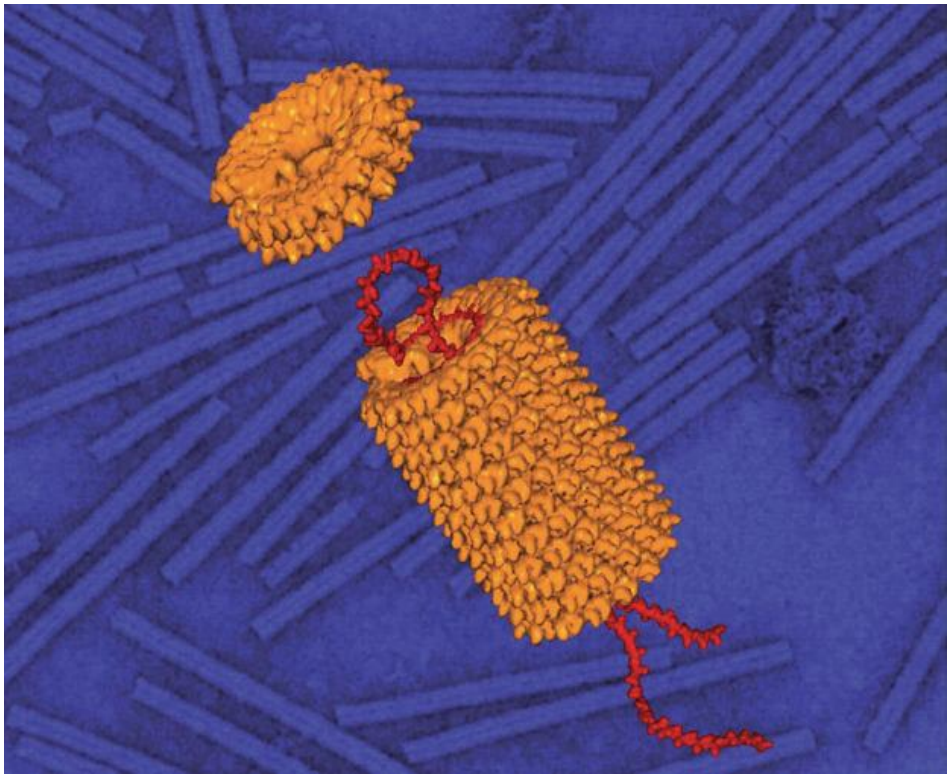
- Unlike other members of the family *Bromoviridae*, the strains of CMV **have a very broad**, collective host range, infecting more than **1200 plant species in over 100 families**, including fruit crops, vegetables and ornamentals, both monocots and eudicots.
- CMV particles are transmitted in a stylet-borne, nonpersistent manner by more than 80 species of aphid in 33 genera, and many symptomless, overwintering weed hosts have been described.
- **Seed transmission** of CMV also occurs in many weeds, although with frequencies ranging from <1% to 50%.

Losses & Control

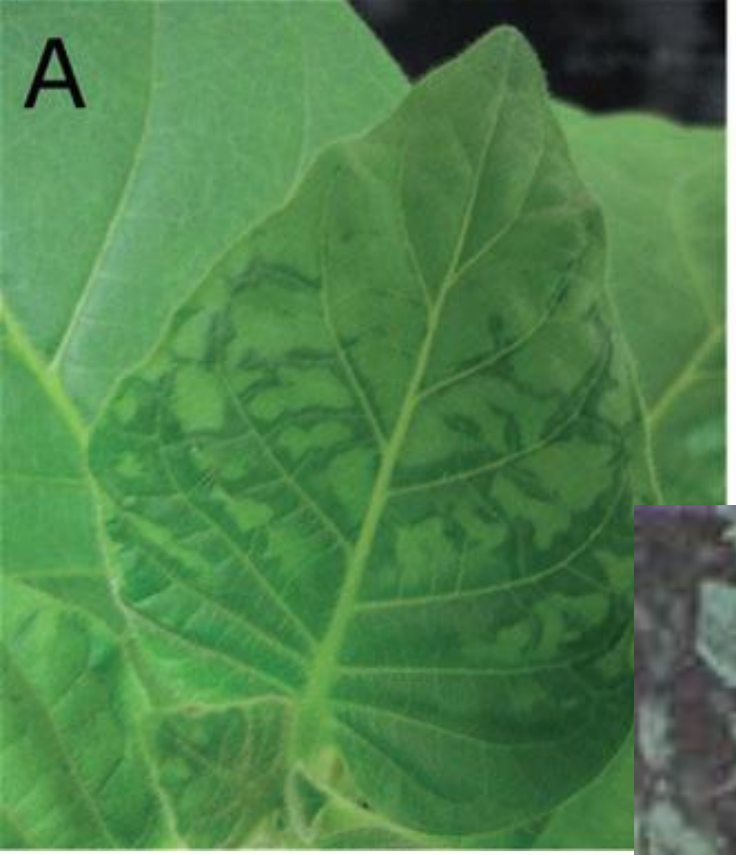
- Although losses in crop yields vary from year to year in different locations and are difficult to quantify, especially when mixed infections are involved, some values for direct effects on crop losses have been reported,
  - e.g. 25%–50% of tomato in China, and 60% of melon and up to 80% of pepper in Spain .
  - When a necrogenic satellite RNA was present, the recorded losses in Spain and Italy were 80% of tomato plants in 70% of the growing regions with losses of 100% in some regions
- Control of CMV in the field by **controlling its aphid vector** is not very effective, although resistance genes have been utilized in several instances.
  - However, many of these genes are for tolerance and others can be overcome by different strains of CMV.
- **Pathogen-derived resistance** offers the best hope for durable resistance to CMV, but currently this approach is not politically popular.

Tobacco mosaic virus (TMV)

- Tobacco mosaic virus (TMV) has been **voted as the most important plant virus** in this poll of the plant virology community.



- TMV continues to be an important teaching system for the classroom, and has developed and maintained its status as **a model system** for more than 110 years, as a result of a plethora of scientific studies initiated from a need to understand how to control TMV-induced disease on tobacco


A


B

The First

- **Martinus Beijerinck** was the first to define TMV as a small infectious entity in 1898 .
- TMV also had a direct role in at least two **Nobel Prizes** (Creager, 2002; Klug, 2010), and many '**firsts**':
  - The first plant virus RNA sequenced
  - The first defined movement protein (MP)
  - The first demonstration of the efficacy of transgenic coat protein (CP) expression for protection from infection
  - The first plant breeding and molecular evidence of a gene-for-gene resistance interaction
  - The first proof-of-principle platform for both nanodevices and the expression of therapeutic monoclonal antibodies and other pharmaceutically relevant proteins (most recently)

What has determined the success of using TMV?

- Early on, the driving interest was **economic**, in that tobacco was an enormously profitable crop.
- However, the interest in TMV soon extended beyond that,
  - TMV became a source of deep scientific curiosity to understand the **physicochemical nature of the virus**, which was determined by Wendell Stanley, a co-worker of Holmes and collaborator with Beale
- More exemplary work followed in the second half of the 20th century showing that :

  (i) the RNA alone was infectious

  (ii) the structure determined by X-ray fiber diffraction resolved the RNA–protein interactions

  (iii) there was a discrete region on the virus for the initiation of encapsidation

  (iv) triplet codons encoded specific amino acids

  (v) the definition of the virus sequence and open reading frames (ORFs)

  (vi) a biologically active cDNA clone.

- This led directly to our **understanding of replication** and the paradigm-shifting findings that the MP bound to the TMV RNA to form thin threads of RNP that could traffic through plasmodesmata, leading another generation of scientists to a new understanding of viruses.

- Similarly, the expression of TMV CP in plants has resulted in the **commercial production of transgenic plants** for virus cross-protection and the realization that this and variants of such methods are effective for other plant–virus systems.

- TMV has also been an agent of discovery with the isolation of the **host N-gene** and ongoing investigations of the molecular mechanisms of its actions (Harries et al., 2008; Kobayashi et al., 2010).

The future looks bright for our ‘favorite’ virus

- More recently, the utility of TMV has been extended, as it has been employed to develop new concepts for computer data storage, to extend our knowledge of the virus structure and carriers of small molecules, and to refine our understanding of the local ecology and fitness of mechanically transmitted viruses
  - Ref. (Kendall et al., 2007; Sacristan et al., 2011; Steinmetz et al., 2008; Tseng et al., 2006).

- Moreover, plant biology is benefitting greatly from TMV, which has pointed the way to the elaboration of functional host–virus interactions, including the mechanics of cell-to-cell movement through the plasmodesmata and RNP trafficking from the nucleus to the cytosol
  - Ref. (Amari et al., 2010; Harries et al., 2009; Hofmann et al., 2009; Kathiria et al., 2010; Komarova et al., 2010; Ruggenthaler et al., 2009).