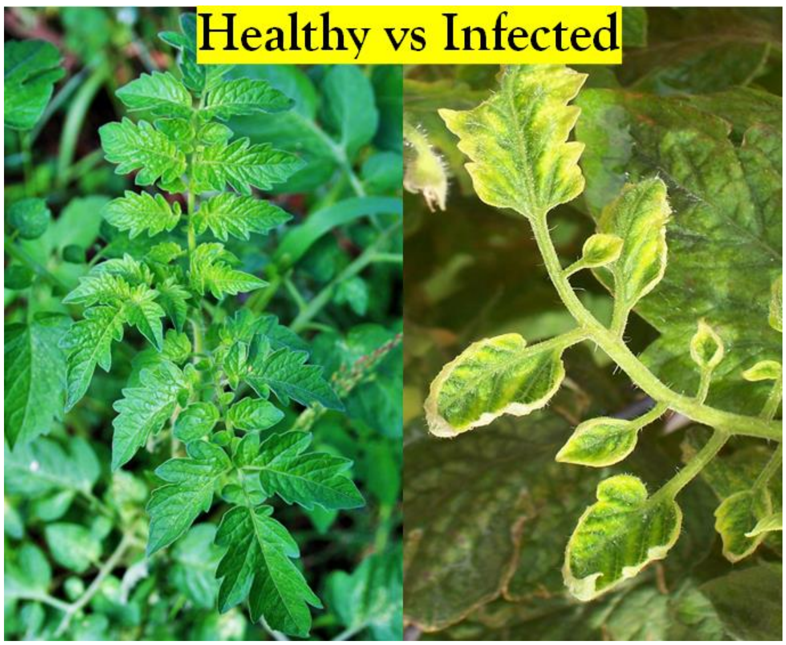
Viruses of Plants

Daddy: what are those pale patches on the tomato plants you bought me to grow?



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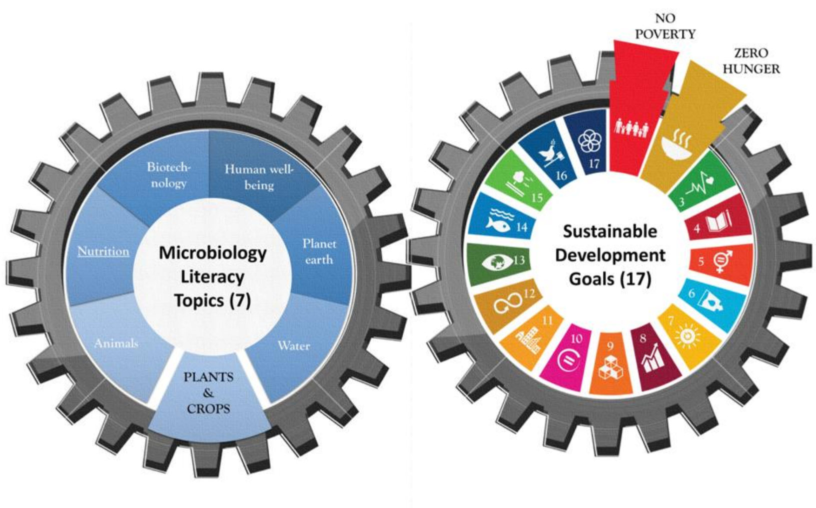
Viruses of Plants

Storyline

Gardening as a habit has proven to be a powerful stress reliever. Not only does it de-stress, but also provides delicious treats such as fresh fruits and veggies to nourish our bodies. Have you ever observed, yellow/white patches in plants either in your garden or in crop fields? These are probably viruses which make plants sick. Like SARS-CoV-2, there are viruses that infect plants and cause a variety of diseases leading to massive crop losses worldwide. In fact, the fascinating world of viruses was first unveiled in a tobacco plant during the 1890's with the discovery of the virus commonly known as Tobacco mosaic virus (TMV). There are multiple modes of virus transmission in plants, but the most effective ways of viral transmissions are through vectors and seeds. When a virus infects a plant, the infected plant shows a range of symptoms depending upon the type of infection, such as yellowing of leaf, either in patches or the whole leaf, curling of leaf, stunted growth of the plant, and abnormalities in flowering and fruit formation. The focus of this lesson is to provide an overview of plant viruses and their common manifestations. We will also discuss major approaches for managing these infections

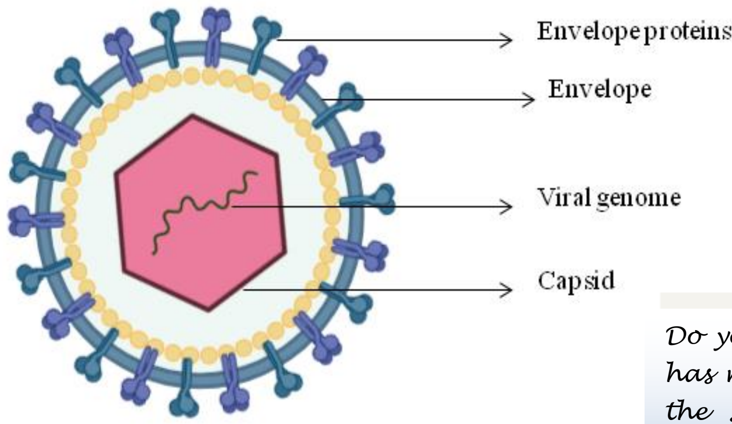
The Microbiology and Societal Context

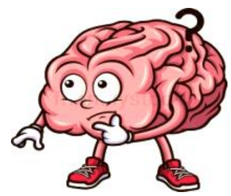
The microbiology: plant viruses; virus vectors; plant infections. *Societal Context*: poverty; hunger



Viruses of Plants: The Microbiology

1. ***Introduction to plant viruses***. A virus is a submicroscopic infectious agent, primarily made up of nucleic acid and proteins. Structurally, it contains genetic material termed the viral genome, covered by a protein called the capsid. In addition to the capsid, some viruses also have a lipid membrane encasing the capsid, known as an envelope. Viruses are not considered to be a living organism because they are unable to reproduce on their own. They have a parasitic mode of lifestyle which requires host cells to grow and perpetuate. Viruses are often referred to as connecting link between living organisms and non-living entities.





Do you know, the human body has nearly 40,000 proteins and the simplest virus has only 4 proteins? Still, they can infect plants and animals.

The size of the virus particle varies from 30-100 nanometers (nm; for comparison, a sheet of paper and a human hair are about 100,000 nm thick). They are so small in size that they can pass through even the finest of filters which block microbes (in fact, they are often separated from microbes by passing samples through such filters). A virus is also an exception to biology as no organisms can be crystallized but viruses can be. They do not have a cell membrane and thus called acellular i.e. do not belong to cellular entities. Thus, viruses can be defined as "**the intracellular parasites which are acellular, filterable and submicroscopic; made up of proteins & nucleic acid and capable of directing their own replication**".

2. ***History of plant viruses.*** The first virus discovered was a plant virus, which was reported in 1892 by **Dimitri Ivanovski**, a Russian botanist who first described the presence of an infectious agent in tobacco plants. From his experiments, he concluded that the sap of leaves infected with mosaic disease (viral disease with mottled discoloured leaves) retains its infectious nature even after filtration. But he was unable to grow or isolate any infectious material despite multiple attempts. Later, in 1898, a Dutch microbiologist named **Martinus Beijerinck**, first used a Latin phrase 'contagium vivum fluidum' meaning contagious living fluid to describe a virus. He inferred this result based on a series of experimental studies. He allowed the sap of infected plants to diffuse on a thick agar surface for ten days and after that he infected healthy plants with the extracts isolated from the deeper layers of agar, avoiding the contamination from the upper layer. To his surprise, he could elicit the same infection in healthy plants using the deep layer extract. He was thus able to conclude that the disease was caused by an agent that was not a bacterium (*contagium fixium*). According to his explanation, the term 'fluidum' referred to a soluble substance causing mosaic disease, not water-like liquid.

After the death of **Beijerinck** in 1931, in less than a decade, scientists began to realize the importance of his study. In 1935, this virus was crystallized – the process of molecules in solution organising themselves in a regular lattice to form a particle, a crystal, as exemplified by the formation of sugar or salt crystals – by **Wendell Meredith Stanley**, who in 1946 won the Nobel Prize in Chemistry for his work. Together, these discoveries laid the foundation of virology.

Literature suggests that humans have been aware of plant disease mediated by viruses even before their first isolation. A poem written by Japanese empress Koken in 752AD describes yellow leaf pattern which strikingly resembles the disease caused by Geminivirus. Similarly, the tulip breaking disease was first described in 1576 and was a highly valued quality during the 'Tulip mania' period in the 17th century.

A tulip flower infected with virus showing colour variegation.

3. *Plant viruses: merely agents of destruction or an essential component of the global ecosystem?* Plants represent the largest body of biomass on planet Earth and constitute more than 80% of the global biological material. For a long time, there has been a widespread view of plant viruses being pathogenic and causing damage to economically important crops and ornamental plants. While to a large extent, this perception is true, there are also reports on virus biodiversity which indicates that, during their lifetimes, plants are infected with numerous viruses, some of which apparently do not have any ill effects.

Here arises an intriguing question, what's their significance then? You would be astonished to know that there are some beneficial viruses which enhance the beauty of ornamental plant species? One such example is the *Tulip breaking virus*, well-known for its dramatic effect on the coloration in tulip flowers. Due to viral infection, color variegation (appearance of differently colored zones) appears in the flowers due to local intensification, fading or over-accumulation of pigments. Other beneficial viruses include Cucumber mosaic virus, Brome mosaic virus, Tobacco mosaic virus, Tobacco rattle virus, *etc*., which confer tolerance towards drought and freezing temperatures. Yet another virus by the name White clover cryptic virus suppresses nodulation thereby preventing nitrogen fixation when adequate nitrogen is present in the soil.

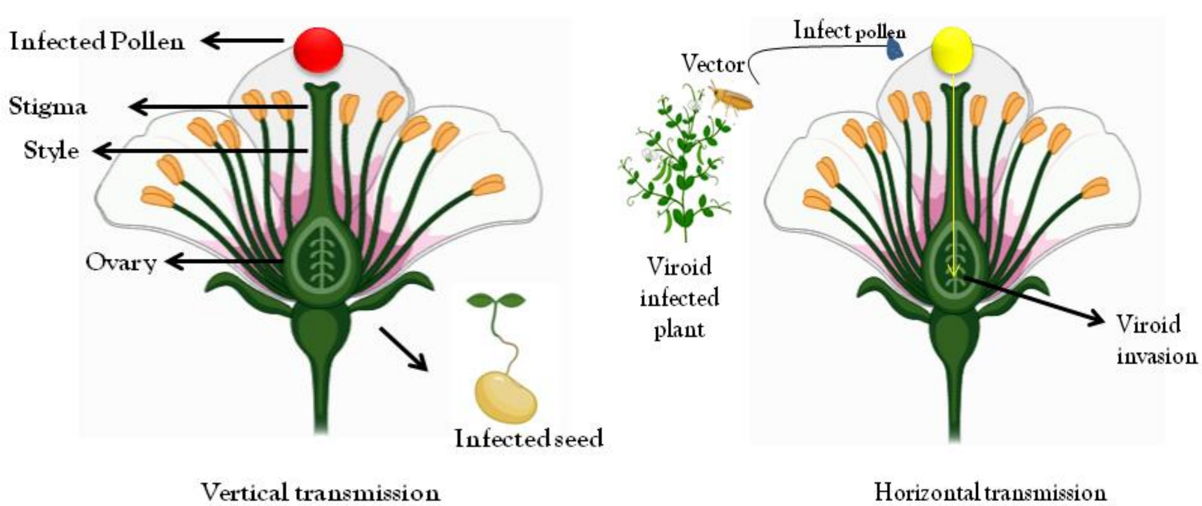
4. *Plant viral diseases & symptoms:* In plants, a viral infection can manifest itself either macroscopically (visible to the naked eye) or microscopically (too small to be seen). Generally, macroscopic symptoms are observed near the point of viral entry. There can be tiny pinpoints or large necrotic areas. The general appearance is characterized by chlorotic lesions (leaf tissue turning yellow due to a lack of chlorophyll), necrotic legions (dead body tissue), or ring spots.

Unlike macroscopic symptoms, microscopic symptoms manifest themselves as anatomical (body structure) or histological (microanatomy of cells, tissues) changes within the infected tissue. These conditions present with necrosis, hypoplasia (underdevelopment of a tissue or organ) and hyperplasia (increased cell production in a normal tissue or organ).

There are a wide range of symptoms in leaves, from mosaic patterns to crinkled and discoloured yellow leaves. Plants infected with viruses may also exhibit a number of abnormalities, such as galls, tumours, stem pitting, and plant stunting.

Different types of symptoms in virus-infected plants A. Tobacco leaf infected with TMV; B. Pepper plant infected with TSWV; C. Tomato plant infected with TYLCV; D. Leaf of cucumber plant infected with CMV; E. A potato infected with PVY.

5. Transmission and spread of plant viruses. Unlike animal viruses, the transmission of plant viruses is rarely through direct contact. There are multiple modes of virus transmission in plants such as vectors, parasitic plants, contaminated soil, water, natural root grafts, seeds etc. However, viral transmission through pollens/seeds and vectors have been documented as the most efficient of all. The transmission of viruses from seeds or pollens is referred as vertical transmission, *i.e*. the transmission of viruses from parents to offspring; whereas the transmission of the virus from a vector is referred as horizontal transmission i.e., the viruses are transmitted into the individuals of the same generation i.e., plants growing adjacent to one another.



The modes of virus transmission in plants: Vertical transmission and Horizontal transmission.

Among these two modes of transmission, vector-mediated transmission is the most epidemiologically and ecologically important mode of transmission. Vectors are living agents that acquire an infectious pathogen from an infected organism and transmits it to other susceptible organisms. Vectors include fungi, nematodes, arthropods (insects) and even some protists. Insects with needle-like mouthparts are best suited for the job of transmission as they use it for sucking the sap from the plant cells.

Plant Virus Vectors: A. Thrips; B. Aphid; C. Whitefly; D. Grasshopper; and E. Caterpillar

There are two different mechanisms whereby viruses are transmitted by vectors:

a. **Non-persistent or non-circulative mechanism**: In this, viral particles from the infected host are picked up by the vector and are reversibly attached to the components of mouthparts or other body parts. They then are transferred to new/healthy plants visited by the vector, without being circulated inside the insect body.

b. **Persistent or circulative mechanism:** In this, the virus circulates through the vector's digestive system, then the haemocoel (the insect's body cavity which contains haemolymph, the equivalent of blood) and finally enters the salivary gland. From the salivary gland, the viral particles pass into fresh saliva which is subsequently deposited on new/healthy plants when the vector feeds on plant tissue. In this case, the vectors remain infectious for a long time.

You would be amazed to know that the viruses transmitted by insects also manipulate insect behaviour, either by making infected plants more attractive or by causing infected plants to produce certain chemicals which upon ingestion promote transmission. In contrast, certain viruses which are not transmitted by the insects may enhance the likelihood of host plant survival by discouraging insects from feeding them.

Viruses which are persistently transmitted by insect vectors show host-specificity, i.e. they can only exploit certain closely-related species of insects.

The major plant viruses, their host plants and transmission methods.

S.No.	Virus	Host Plant	Mode of Transmission/Vector	Disease
1.	*Tobacco mosaic virus* (TMV)	Tobacco, Tomato	Multiple ways: spread from plant to plant via direct contact, from seeds and vectors (grasshoppers and caterpillars)	*Tobacco mosaic disease*
2.	*Tomato spotted wilt virus* (TSWV)	Multiple host plants including Tomato, onions, peanut etc.	Thrips	Spotted wilt disease
3.	*Tomato yellow leaf curl virus* (TYLCV)	Tomato, Beans, Ornamental plants etc.	Whiteflies	Tomato yellow leaf curl disease
4.	*Cucumber mosaic virus* (CMV)	Cucumber, Melon, Pumpkin, Watermelon, Squash etc.	Several aphid species	Cucumber mosaic disease
5.	*Potato virus Y* (PVY)	Potato, capsicum, tomato, brinjal and tobacco	Multiple ways: Contact transmission, through seeds and vectors (Aphids)	Potato tubers necrotic ringspot disease
6.	*Potato virus X* (PVX)	Potato, Tomato, Tobacco etc.	Contact transmission and through vectors (Grasshoppers)	Rugose mosaic disease (PVX together with PVY)
7.	*Cauliflower mosaic virus* (CaMV)	Cauliflower, radish, turnip, mustard, broccoli, and cabbage etc.	Aphids	Cauliflower mosaic disease

6. ***Classification of plant viruses.*** Like all organisms, viruses also contain DNA or RNA as genetic material. However, we often assume DNA as double-stranded and RNA as single-stranded, but the world of viruses is an exception. A virus can have a genome consisting of single-stranded RNA (ssRNA), double-stranded RNA (dsRNA), single-stranded DNA (ssDNA) and double-stranded DNA (dsDNA). Some examples are listed below:

S. No.	Genetic Material	Examples
1.	Single-stranded RNA	*Tobacco Mosaic Virus* (TMV), *Tomato Spotted Wilt Virus* (TSWV), *Cucumber Mosaic Virus* (CMV), *Potato Virus Y* (PVY)
2.	Double-stranded RNA	*Rice Dwarf Virus*, White Clover Crypto-virus 1, Wound Tumor Virus (WTV)
3.	Single-stranded DNA	*Tomato Yellow Leaf Curl Virus* (TYLCV), Bean Golden Mosaic Virus (BGMV), Maize Streak Virus (MSV)
4.	Double-stranded DNA	*Cauliflower Mosaic Virus* (CaMV)

7. ***Management of plant viral diseases.*** Controlling plant viruses and preventing the diseases caused by them is one of the major concerns to avoid huge economic losses. If a plant virus is continuously dominating in an area, then crop rotation – each year cultivating a different crop – reduces availability of the host plant and hence reduces virus propagation and transmission. If the virus is transmitted by vectors such as insects, pesticides may be useful to reduce vector numbers and hence transmission. If the virus is transmitted by nematodes, then soil fumigation with a nematicides can be implemented to reduce nematode numbers. If the virus is transmitted through seeds, the use of guaranteed virus-free seeds from reliable sources will diminish local viral loads and multiplication and serve towards bringing down the spread of disease. And, removal of infected plants that show symptoms can also reduce viral transmission to a considerable extent. Viruses infect a variety of plant hosts, so it is sometimes possible to identify other plant hosts in the agriculture field, such as weeds that are not related to crop plants, and remove them to reduce virus levels.

Nowadays, plant varieties have been developed that are resistant to a specific group of viruses which are problematic and sowing such crops has proven to be effective against a broad range of viral diseases. Most importantly, awareness among farmers about pathogenic plant viruses can immensely reduce crop losses from viral disease. Therefore, special training programs to make farmers vigilant of the pathogens, their identification, and the existence of suitable remedial strategies, can substantially help in preventing crop losses. At the same time, awareness about plant viruses at the school level can also ensure a better future of farming.

Relevance for Sustainable Development Goals and Grand Challenges

- **Goal 1: End poverty.** By managing the viral impact on crop production, surplus food can be produced which in turn can be sold, thereby generating income and reducing poverty.
- **Goal 2: End hunger.** Plant viruses are real threat to food security: one estimate is that they cause annual losses amounting to $ 30bn. Without managing plant viruses, it is impossible to achieve sustainable food production systems and resilient agricultural practices. Effective management of plant virus infections can help increase crop yields that enable reduction in hunger.

The Evidence Base, Further Reading and Teaching Aids

Lefeuvre, P.; Martin, D. P.; Elena, S. F.; Shepherd, D. N.; Roumagnac, P.; Varsani, A., Evolution and ecology of plant viruses. Nat Rev Microbiol 2019, 17 (10), 632-644.
Valverde, R. A.; Sabanadzovic, S.; Hammond, J., Viruses that Enhance the Aesthetics of Some Ornamental Plants: Beauty or Beast? Plant Dis 2012, 96 (5), 600-611.
Roossinck, M. J., The good viruses: viral mutualistic symbioses. Nat Rev Microbiol 2011, 9 (2), 99-108.

Glossary

Acellular:	Being without cells
Aphids:	A small bug which feeds by sucking sap from plants
Arthropods:	An invertebrate phylum (insects belong to this phylum)
Capsid:	The protein shell of a virus
Color variegation:	The appearance of differently coloured zones
Crop rotation:	Practice of growing different crops in succession on the same area
Crystallization:	The process of obtaining crystals (pure forms)
Envelope:	Outermost layer of many types of viruses
Fungi:	Multicellular eukaryotic organisms represented by molds/mushroom
Geminivirus:	A group of plant viruses with single-stranded DNA genomes
Haemocoel:	Primary body cavity of most invertebrates, containing circulatory fluid
Inoculum:	A material used for inoculation
Nematodes:	Roundworms
Nodulation:	The process of forming root nodules containing symbiotic bacteria
Protists:	A single-celled organism of the kingdom Protista, such as simple algae
Replication:	The biological process of producing two identical replicas of DNA from one original DNA molecule
Sub-microscopic:	Too small to be seen by an ordinary light microscope
Thrips:	A type of insects that suck the juices of plants
Tulip mania:	Tulip mania was a period in the Dutch Golden Age
Whiteflies:	A minute winged bug covered with powdery white wax