A Textbook & Practical Manual Of Arthropod Vectors of Plant Pathogens

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Preface

We indeed, feel a great pleasure to put before you “A text book and practical manual of Arthropod Vectors of Plant Pathogens” for the use of students enrolled in the course in Insect vectors of plant pathogens being given at Sam Higginbottom University of Agriculture, Technology and Sciences, Naini, Prayagraj, Uttar Pradesh, India. This book was written not only as based on BSMA committees syllabus wise other than that this book is reasonably written according to the student’s point of view to make them understand easily with different concepts, this is the main motive for describing this book.

Considering the whole field, it was realized that this book is not only used for the classroom purpose but also used as a reference book for competitive exams. The present book provides recent knowledge on introduction to insect vectors, their characteristics, mouthparts and feeding processes, virus-vector relationship classification, transmission of plant viruses by aphids, whiteflies, thrips, mealy bugs, beetles and weevils, leafhoppers, plant hoppers and mites along with this it includes the integrated management of vectors and different methods of isolation and identification of fungus and bacteria which is carried by insect vectors.

Particular care has been taken to make the language in simple and easy so that students can follow the script without any difficulty. Clear illustrations have also been given where it is necessary.

To complete this book, we have gone through several research papers, articles, factsheets and bulletins. We, therefore express our gratitude to the authors, scientists and the publishers who have generated the aforesaid scientific literature. We also express our gratitude to Brother Chandra sekhar who have given immense support in the pictures of different diseases. We want to acknowledge our Hon’ble Vice-chancellor Bishop (Prof.) Rajendra B. Lal who has always inspired us to accomplish the task. We express our sincere thanks to all our colleagues and friends who always encourage us to bring out the “A text book and practical manual on Arthropod Vectors of Plant Pathogens” which is now before you.

Since, this the first book we are writing there is a possibility of criticism, limitations and suggestions for the improvement from the readers will be gratefully acknowledged.

Special thanks to uncle and my guru Mr, Devarapalli Aseervadam (Police Department, Andhra pradesh), Danny for emotional support and financial support.

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Chapter-1
Introduction

Vector: The term "Vector" comes from Latin word which means 'To carry.'

An organism capable of transmitting pathogens from one host to another is called as **Vector.**

(Or)

Any organism feeding on infected plants and travelling between plants can potentially act as a virus-transport device, and such organisms are designated "vectors."

An insect which acquires the disease causing organism by feeding on the diseased plant or by contact and transmit it to healthy plantsis known as **Insect vector.**

Insects alone are damaging, but their disease vectoring capacity makes them particularly harmful. **(Brault *et al.*, 2010; Sarwar, 2015).**

The insects belong to the order Hemiptera, Thysanoptera, Dermaptera, Orthoptera and Coleoptera are known to have innumerable number of vectors which causes various diseases in plants by transmitting bacteria, virus, fungi and nematodes also. Most vectors of plant viruses are sucking insects, which are present in the order Hemiptera. Their small stylets allow vectors to introduce virus into plant cells or vascular tissues with minimal feeding damage. Example, aphids transmit the greatest variety of plant viruses.

Insect vectors of plant viruses are found in 7 of the 32 orders of the class Insecta. The majority of the vectors are found in the two orders of insects with pierce-sucking mouthparts (number of species in parenthesis): Hemiptera (300) and Thysanoptera (06). Other vector species are found in five orders of chewing insects: Coleoptera (60), Orthoptera (10), Lepidoptera (04), Diptera (02) and Dermaptera (01). **(Fereres, 2015)**

Piercing and sucking type of mouth parts of insects makes them effective vectors of plant viruses. Among them Hemipterans are by far the most important virus vectors, comprising more than 70% of all known insect-borne viruses. Among these, aphids and whiteflies are the major vectors of plant viruses transmitting more than 500 virus species

Plant diseases are generally caused by microscopic organisms such as fungi, bacteria, nematodes, protozoa, and parasitic green algae, that penetrate, infect, and feed off one or more types of host plants; sub microscopic organisms such as viruses and viroids that enter, infect, spread systemically and affect the growth of their host plants.

Insects transmit pathogens, such as many fungi and bacteria, mostly externally on their legs, mouthparts, and bodies. Almost all plant pathogenic viruses, all phytoplasmas, xylem- and phloem-inhabiting fungi and bacteria, some protozoa, and some nematodes are also transmitted by insects, and they are usually carried by the insect internally. The insects that transmit fungi and bacteria externally on their bodies and legs belong to many orders of insects. On the contrary, the insects that transmit the other pathogens are very specialized and specific for the pathogen they transmit and belong to a certain species or genus of insects.

Percentage criteria:

Insects are the most important factors in plant viral, bacterial and fungal diseases.

Insects responsible for viral diseases	-	60-80%
Insects responsible for bacterial diseases	-	08-10%
Insects responsible for fungal diseases	-	15-20%

More than half of the nearly 550 vector transmitted virus species recorded so far are disseminated by aphids (55%), 11% by leafhoppers, 11% by beetles, 9% by whiteflies, 7% by nematodes, 5% by fungi and plasmodiophorids, and the remaining 2% by thrips, mites, mirids, or mealybugs **(Astier *et al.,* 2001).**

The major insect orders are responsible for the transmission of viral, bacterial, fungal and MLO's diseases in plants *viz*.,

1. **Hemiptera**: Hemipterans are by far the most important virus vectors, comprising more than 70% of all known insect-borne viruses. Among these, aphids and whiteflies are the major vectors of plant viruses transmitting more than 500 virus species.

a) **Aphids** (Aphididae: 192 species, 275 viruses)

The aphids (Aphidinae) are by far the most important family among these vectors, transmitting many more viruses than Whiteflies (Aleyrodidae), leaf hoppers (cicadellidae), or plant hoppers (Delphacidae).

Morethan 4700 aphid species have been described **(Remaudiere and Remaudiere, 1997)** and of these, over 192 have been reported to transmit plan viruses **(Nault, 1997)**.

The majority of the reported aphid virus vectors belong to the genera *Myzus,* Aphis, Acyrthosiphum and Macrosiphum in the sub family Aphidinae **(Kennedy *et al*., 1962)**.

55% of the viral diseases are transmitted through aphids.

Important species are-

Aphis gossypii

Aphis craccivora

Myzus persicae- which transmits maximum number of viral diseases

b) **Whiteflies** (Aleurodidae: 3 species, 43 viruses)

There are more than 1500 species of whiteflies belonging to 161 genera across the world. **(Hardy, 2018)**

Begomoviruses, which constitute the largest genera within *Geminiviridae* are transmitted by *B. tabaci*. The genomic size of begomoviruses (monopartite or bipartite) ranges from 2.7 to 3.0 kb **(Saad *et al*., 2021)**

Important species are-

Bemisia tabaci – which transmits maximum number of viral diseases
Bemisia gossypiperda
Aleurotrachelus socialis

c) **Leafhoppers** (Cicadellidae: 49 species, 31 viruses),

Leafhoppers (family Cicadellidae) transmit over 80 known types of plant disease, including ones caused by viruses, mycoplasma-like organisms, and spiroplasmas (**Sarwar, 2020)**.

Important species are-

Orosius albicinctus

Nephotettix virescens

d) **Mealy bugs** (Pseudococcidae: 19 species, 10 viruses)
It is estimated that 149 mealybug species feed on plants with their piercing and sucking feeding behavior. The Planococcus species are the most common and destructive. **(Cox, 1989)**

Important species are-

Planococcus citri
Dysmicoccus brevipes
Ferrisia virgata

e) **Planthoppers** (Fulgoridae)

Important species are-

Nilaparvata lugens

2. Thysanoptera: Thrips (10 species, 11 viruses)

It includes thrips. Approximately, 7,700 species of thrips have been recorded out of which only less than 1% is considered as pests of crops. Most of the thrips species belong to the family Thripidae and are phytophagous. Only a few viruses are transmitted by thrips, but their economic impact is internationally important. *Thrips tabaci* and *Frankliniella* species are carrying 'Tomato Spotted Wilt Viruses'. These viruses cause 'Spotted Wilt' disease in tomato, tobacco, dahlia and pineapple in Africa, Asia, Australia, Europe, North and South America.

3. Orthoptera: Grasshopper (27 species)
The order Orthoptera includes the grasshoppers, crickets, and their relatives

4. Coleoptera: Beetles (70 species, 42 viruses)

Coleoptera is the largest insect order accounting for over 360,000 species, which constitutes 40% of the known insect species in the world. Beetles are not mentioned in the first place as disease vectors, but some of them cause considerable damages through the transmission of plant pathogens.

It includes flea beetles, mustard beetles, corn flea beetles, cucumber beetles, etc. Some important viruses require leaf beetle or weevil vectors. Viruses transmitted by beetles through feeding that inoculate the virus into plants. Wood-boring beetles (Cerambycidae) serve as vectors of nematodes.

5. **Dermaptera**: Earwigs

Earwig, ***Forficula auricularia*** carry 'Turnip Yellow Mosaic Virus' and causes 'Turnip Yellow Mosaic' viral disease in turnip, cauliflower and cabbage at different parts of the world.

6. **Acari:** Mites

Mites are minute to small and range from 300 to 500µm in body length. Many worm mites (Eriophyidae), false spider mites (Tenuipalpidae) and spider mites (Tetranychidae) which possess piercing and sucking mouthparts are known as vectors of virus diseases of cereals, fruit trees, pigeon pea and coffee plants. (**Jeppson *et al*, 1975; Slykhuis, 1969**). Among the Acari, only the Eriophyoidea are important vectors of plant pathogens. The relationship between eriophyid vector and transmitted agent is highly specific.

Plant diseases are also caused by abiotic, environmental factors such as nutrient deficiencies, extremes in temperature and soil moisture, etc. that affect the normal growth and survival of affected plants.

Many of the microscopic organisms and of the viruses are transmitted by insects either accidentally (several fungi and bacteria) or by a specific insect vector on which the pathogenic organism (some fungi, some bacteria, some nematodes, all protozoa causing disease in plants, and many viruses) depends on for transmission from one plant to another, and on which some pathogens depend on for survival.

Spread and development of plant diseases by insects:

Insects transmit pathogens in three main ways.

1) Many insects transmit bacterial and fungal spores passively by feeding in or walking through an infected plant area that has on its surface plant pathogenic bacteria or fungal spores as a result of the infection. The bacteria and spores are often sticky, cling to the insect as it moves about, and are carried by it to other plants or parts of the same plant where they may start a new infection.
2) Some insects transmit certain bacteria, fungi, and viruses by feeding on infected plant tissues and carrying the pathogen on their mouthparts as they visit and feed on other plants or plant parts.
3) Several insects transmit specific viruses, phytoplasmas, protozoa, nematodes, and xylem- and phloem-inhabiting bacteria by ingesting (sucking) the pathogen with the plant sap they

eat. Subsequently, the pathogen circulates through the body of the insect until, with or without further multiplication in the insect; the pathogen reaches the salivary glands and the mouthparts of the insect through which it is injected into the next plant on which the insect feeds.

Importance of Insect Vectors

Most plant viruses depend on vectors for their survival for two principal reasons:

1) An impermeable cuticle coats the plant epidermis, preventing entry of virus particles (animal viruses enter readily through natural openings). Most vectors are insects (non-insect vectors include mites, nematodes and fungi). Several plant viruses may spread by contact or vegetative reproduction. Many insects such as hemipterans are well adapted to their role as vectors by their capacity to pierce the epidermis and delicately deposit the virus in the cytoplasm without risking the integrity of the plant cell. Recent findings propose that viruses have adapted to their vectors modifying their behaviour to maximize their own spread.
2) Plants are rooted and lack independent mobility. Therefore, many viruses depend on insects for transport among hosts (unlike animals that, by their own mobility, transport the virus to new niches). **(Fereres, 2015)**

Chapter -2
Insect vectors and their characteristics, Mouth parts and feeding processes

The most important vector groups, with the number of vector species and viruses transmitted, are listed below.

Hemiptera which includes,

Aphids (Aphididae: 192 species, 275 viruses)

They are soft bodied and oblong shaped. Many species of aphids alternate between a primary and a secondary host, although there are many variations of aphid life cycles depending on the aphid species and on climate. Some aphids overwinter as parthenogenetic viviparous forms while others go through their life cycle on one host species or on several related species.

Aphids have mouthparts that consist of two pairs of flexible stylets held within a groove of the labium. During feeding, the stylets are extended from the labium and, through a drop of gelling saliva; the stylets rapidly penetrate the epidermis. Penetration may stop at the epidermis or it may continue into the middle layers of leaf cells with a sheath of saliva forming around the stylets. The stylets move between the cells until they reach and enter a phloem sieve tube from which the aphids obtain their food. Both acquisition and transmission of virus by aphids are affected by temperature, humidity and light.

Leafhoppers (Cicadellidae: 49 species, 31 viruses), and Plant hoppers (Fulgoridae: 28 species, 24 viruses)

Adults are elongated, wedge shaped and somewhat triangular in cross section. They all feed by sucking sap by Piercing-sucking type of mouthparts from phloem elements of plants. Their feeding behaviour is similar to that of aphids in that the mouthparts, surrounded by the salivary sheath, penetrate the phloem of host plants.

Whiteflies (Aleyrodidae: 3 species, 43 viruses)

Adult whiteflies have yellow- white, wedge shaped bodies and white wings and which resembles white moths. The waxy powder on their wings and bodies is very similar to that of mealy bugs.

The first instar among the larvae is mobile. Whiteflies produce many generations in a year and reach high populations. Only a few species of whiteflies transmit viruses, mostly in the tropics and subtropics, but the viruses they transmit cause very severe diseases. Mouth parts

composed of the labrum, the labium and the stylets. The stylet bundle is the feeding organ of the whitefly and is composed of two mandibular stylets and two maxillary stylets.

Mealy bugs (Pseudococcidae: 19 species, 10 viruses)

Mealybugs (family: Pseudococcidae) are soft-bodied, wingless insects that often appear as white cottony masses on the leaves, stems, and fruit of plants. Mealybug bodies are distinctly segmented and usually covered with wax. Older individuals may have wax filaments around their body margins. They feed by inserting long sucking mouthparts, called "stylets," into plants and drawing sap out of the tissue. Most species of mealy bugs are white, off-white or grey; some species are yellow, pink or orange.

Mealy bugs are important as virus vectors primarily on some perennial plants in the tropics and subtropics. They move slowly on plants and therefore are not as efficient virus vectors. They move from plant to plant, mostly as crawling nymphs, through leaves of adjacent plants being in contact with each other; by ants tending the mealy bugs and moving them from one plant to the other; and occasionally by wind.

They have piercing and sucking mouthparts composed of clypeo-labral shield and three segmented labium with a groove on its anterior face containing the stylet fascicle. Fourteen pairs of different types of sensilla cover the exposed surface of the labium.

Some treehoppers (Membracidae, 1 species, 1 virus), contain by far the largest number and the most important insect vectors of plant viruses, but the true bugs (Hemiptera, 4 species).

Thrips (Thysanoptera: 10 species, 11 viruses)

Most adult thrips are elongate, slender, and minute and have long fringes on the margins of both pairs of their long, narrow wings. Nymphs are oblong or slender and elongate and lack of wings.

Thrips are polyphagous insects that have many hosts. Some of the vector species reproduce mainly parthenogenetically. The larvae are rather inactive but the adults have wings and are very active. Thrips adults feed by sucking the contents of sub epidermal cells. The thrips mouthparts are composed of two maxillary stylets and one mandibular stylet (Right mandible is rudimentary or absent) hence these mouthparts known as **Asymmetrical** and that form a feeding apparatus. Adults live up to 3 weeks and there may be as many as 20 generations per year.

Beetles (Coleoptera: 60 species, 42 viruses)

Beetles have front pair of wings, which are highly sclerotized and helps in protective membranous hind wings called as Elytra. They have prognathous head and the mouth parts possess forwards.

There are more than 60 vector species in the order Coleoptera (beetles), 30 of them in the family Chrysomelidae. Most beetle vectors are tend to eat plant cells between the leaf veins and regurgitate during feeding, thereby bathing their mouthparts with sap and virus. Beetles can acquire and can transmit the virus after feeding for a few seconds and they can retain the virus from 1 to 10 days.

Grasshoppers (Orthoptera: 27 species)

The order Orthoptera includes the grasshoppers, crickets, and their relatives. The order comprises two suborders, Caelifera (grasshoppers, locusts, and mole crickets) and Ensifera (true crickets, katydids, and bush crickets). Members belonging to Caelifera have short antennae and abdominal tympanal organs (ears), whereas antennae of the Ensifera reach at least to their abdomen and their ears are located in their fore tibia (front legs).

They occasionally carry and transmit a few viruses with the help of their mouth parts. (Biting and chewing mouthparts).

Earwig (Dermaptera)

Adult earwigs (Dermaptera: Forficulidae) have uniform brown and long slim bodies with light brown or yellow legs and pincers (also called "forceps," which are long and curved in male earwigs, while those of females are almost straight) on the back of their abdomen. European earwig, *Forficula auricularia* L., is a polyphagous insect that damages vegetables and flowers in gardens and greenhouses. These feed on the shoots of young seedlings, damaging the plant so that it will not be able to yield a crop. They also feed on soft plant shoots, such as corn silk, and eat small holes in foliage and flowers, and sometimes ripened fruits are infested. **Markham and Smith (1949)** reported the transmission of the turnip yellow mosaic virus by this earwig to crucifers under laboratory conditions.

Virus transmission by pollinating insects

Honey bees and other pollinating insects seem to play a role in distributing virus-infected pollen from infected plants to healthy ones. It appears, however, that no special mechanisms or involvement of the insect are present in such virus transmission.

Chapter -3
Virus vector relationship

Virus transmission consists of at least three step-wise processes:

(i) The uptake of virus from an infected source (**acquisition**).
(ii) The stable **retention** of acquired virions at requisite sites within the vector.
(iii) The release of bound or retained virions and their delivery to a site of infection (**inoculation**). **(James and Perry, 2004)**

Two major classifications of viruses have been proposed:

1. Virus vector relationship based on site of retention of the virus in vector

Kennedy *et al.,* (1962) coined the virus- vector relationships as follows depending upon whether they are retained in the haemocoel of the vector. Within these classes, subdivisions can be identified on the basis of specifics of their retention and replication within the vector.

a) Non circulative (Stylet borne or Non-persistent): The virus carried in the stylets and they do not reach the midgut. Noncirculative pathogens do not enter the haemocoel of their arthropod vectors but are characterized by association with specific body parts of the vector, typically mouthparts and foregut, but including structures such as mycangia for fungal pathogens. Their association with the vector is sometimes facilitated by binding of pathogen particles or virions to specific proteins on mouthparts **(Ugest *et al*., 2007)** or foreguts **(Chen *et al.,* 2011)** of vectors. The vector has to feed freshly whenever it transmits a virus *i.e.,* it loses its infectivity after single transmission. E.g.: Aphids.

b) Circulative (Persistent or Non-stylet borne): The vector remains to be viruliferous for rest of its life i.e. The infectivity lasts until its death and no need to feed regularly whenever it transmits the virus. Virus is not carried out in the stylets and they reach midgut. Circulative pathogens are those that reside for some period of time within the vector haemolymph. Circulative viruses and bacterial pathogens that can be classified with them pass through cells of the gut lining to enter the haemolymph. They typically move to salivary glands and salivary ducts, where they can be transmitted to a new host. Acquisition and transmission require sustained feeding for hours, and transmission is only possible following a latency period.

Circulative pathogens may further be classified as **non-propagative or propagative**, depending upon whether they replicate within the vectors. Some viruses and all bacterial pathogens are propagative. Circulative pathogens are generally characterized by a high degree of vector specificity, with one or several closely related vector species **(Nault, 1997; Ng and Perry, 2004).** E.g.: Leaf hoppers, whiteflies, thrips.

2. Virus vector relationship based on virus retention time by the vector

Watson and Roberts (1939) gave the basic concepts of virus vector relationship on the basis of the method of transmission and persistence (Retention time) in the vector, viruses may be classified into three categories.

a. Non-persistent (stylet borne): The term 'stylet borne' coined by **Kennedy, Day and Eastop.** More than 100 plant viruses are transmitted in a non-persistent manner. These viruses are rapidly acquired during vector probing of virus-infected plants, in cases of non-persistent vectors, virus acquisition time is short (seconds), inoculation time short, latent period zero, and retention time minutes to hours (viruses acquired within seconds and retained for only a few minutes by their vectors). The insect can inoculate the virus without delay into another plant equally rapidly. Transmission can thus be accomplished in an extremely short time.

In general, the vector retains the virus for only a few minutes or hours, which is why this type of transmission was called "nonpersistent by **Watson and Roberts, (1939)**. The transmitted virus does not enter the midgut of the vector and therefore is lost whenever the vector moults. Transmissible virus is believed to be confined to the vector's stylets and or foregut.

In general, non-persistently transmitted viruses are stable and occur in relatively high concentration in epidermal cells of their plant hosts. Many are long flexuous rods, such as those in the potato virus Y group. Practically all (about 98%) non persistent transmission is by aphids.

b. Persistent: More than 80 plant viruses and all plant MLOs and RLOs are transmitted by several different vector taxa in a persistent or circulative manner. or persistent vectors, virus acquisition time is minutes, inoculation time minutes, latent period one or more days, retention time through molt or for life, and vector specificity high (with viruses that require minutes to hours for acquisition and that can be retained for very long periods, often until the vector dies). The pathogen circulates within the body of the vector, hence **Black's** term. "Circulative" **(Black, 1959)**. These pathogens enter the body cavity via the midgut and thus are retained through moults.

c. Semi persistent: A few plant viruses are transmitted in a manner that Sylvester termed semi persistent **(Sylvester, 1956).** Acquisition and inoculation require longer periods than for non-persistent transmission, usually several minutes to an hour. The virus is also retained longer, although still not through moults. **(Black, 1984; Ng and Perry, 2004)** The longer a vector is allowed to feed on a source plant, the longer it will be able to inoculate the virus. This is not true for non-persistent transmission, in which acquisition efficiency declines during long feeds. The viruses transmitted in s semi persistent manner are a heterogeneous group; for example, beet yellows and strawberry vein banding viruses are transmitted by aphids and rice tungro and maize chlorotic dwarf viruses by leafhoppers.

Viruses exhibit all four transmission mechanisms: (a) non-circulative, non-persistent; (b) non-circulative, semi-persistent; (c) circulative, non-propagative; and (d) circulative, propagative **(Ng and Perry, 2004).** Fungi are non-circulative but may be propagative or non-propagative, depending on the transmitted life stage (spores, in a yeast-like state, or as mycelia), and persistent, semi-persistent, or non-persistent. In contrast, bacterial pathogens use circulative, propagative transmission.

"Circulative-non-propagative" has been used to describe pathogens that do not multiply in the vector, and "circulative-propagative" to describe pathogens that do; these terms are often shortened to circulative and propagative, respectively. Watson and Roberts' term "persistent" covers both types of transmission and refers to the fact that these pathogens can be retained in their vectors for long periods of time **(Watson and Roberts, 1939)**. Circulative- non-propagative pathogens have shorter latent periods (a few hours or days) in their vectors than circulative-propagative ones (several days or weeks). A pathogen that multiplies is often retained for the life of the vector and is sometimes passed to progeny through the egg (transovarial passage).

Differences between non-persistent (stylet borne), semi persistent and persistent

Particulars	**External (Non-circulative)**		**Internal (Circulative)**
	Non persistent (stylet borne)	**Semi persistent (stylet borne)**	**Persistent**
Mechanical transmission	Yes	No	No
Tissue of virus acquisition	Epidermis and parenchyma	Mesophyll, phloem and parenchyma	Mostly phloem
Acquisition period	Low (from seconds to minutes)	More (Minutes to hours)	More (hours to days)
Latent period	Not required	Not required	Required (Hours-Days-Weeks)
Period for which vector remains infective (Retention time) or (Persistent)	Usually less than 4 hours but can be up to 10 hrs.	10-100 hrs.	More than 100 hrs.
Replication of virus in vector	No	No	Yes ,in some vectors
Retention of virus through moulting (Transovarial transmission)	No	No	Yes
Sequential Inoculation	Low (Seconds to minutes)	More (Seconds to minutes)	More (Minutes to hours)

Virus vector specificity	Low	intermediate	High
Location of virus in vector	Externally or near mouthparts	Near the junction of stylet and tip	Internally in Haemolymph
Time of dispersion	Short	To be continued	Long
Vectors	Aphids and Mites	Aphids, Beetles, Leaf hoppers, Mealy bugs, Whiteflies	Aphids, Beetles, Leaf hoppers, Mites, Thrips, Nematodes, Bugs, Fungi, Whiteflies
Symptoms	Mosaic type of diseases	Yellowing	Leaf roll and yellowing
Examples	Bean yellow mosaic Soybean and cowpea mosaic virus	Cauliflower mosaic virus and beet yellow virus	Potato leaf roll and citrus Tristeza virus

Note: All circulative viruses except *Pea enation mosaic virus* (PEMV) are transmitted in a persistent manner. PEMV is assisted by an umbra virus that allows the virus to invade tissues other than phloem and duration of the acquisition and inoculation periods is similar to viruses transmitted in a non-persistent manner.

(Fereres, 2015)

Acquisition period: It is the time for which an initially virus free vector is allowed to access to a virus source *i.e.,* virus to infected plant materials.

Latent period: the time between acquiring the virus by the vector and the ability to transmit it.

Inoculation period: It is the time for a virus carrying vector is allowed access to a virus free plant and could feed on it.

Retention/ Persistence: It is the time for which a vector remains infective even after leaving a virus source.

3. A third classification was proposed based on the localization of virus–vector retention sites: cuticula-borne or salivary gland-borne.

4. Transmission of plant viruses can occur either horizontally or vertically, or both. Horizontal transmission is support to increase demonstratively disease prevalence and infection under highly favorable conditions such as high susceptible host population density, high inoculum levels, and high virus replication rates. Vertical transmission results in long-term virus persistence in the vector. Vertical transmission supports the evolution of benign infection. According to **Chen *et al.* (2006)** any plant-virus infection can follow two transmission processes. Plant virus transmission can be occurring through the following two pathways in the nature.

a) **Horizontal transmission:** Horizontal transmission is carried by external agents such as insect vectors, human activities, pruning, agriculture tools, and other direct or external

contamination. In this pathway of transmission, viruses are directly or indirectly transmitted among individuals of the same generation. In direct horizontal transmission, plant viruses are transmitted by a direct route such as airborne infection and food-borne infection, whereas in indirect transmission, plant viruses are transmitted through intermediate biological vectors such as aphids, whiteflies, and leafhoppers, which acquire and transmit virus from diseased plant to healthy plants.

b) Vertical transmission: Vertical transmission occurs when a virus's goes in to the progeny from the infected parent's plant either through asexual propagation such as cuttings, grafting, and budding etc. or in sexual reproduction via infected seeds. In this pathway, viruses are passed vertically from mother to offspring via egg, either on the surface of the egg, called "transovum transmission," or within the egg, called "transovarian transmission" **(Clayton and Tompkins, 1994; Ewald, 1994).**

5. The transmission of plant diseases can also be classified as direct or indirect, depending on whether the pathogen is transferred directly through planting material or indirectly via vectors or environmental factors.
    a. **Direct transmission** occurs when pathogens are transferred to a new host along with the planting material itself. This involves pathogens residing within or on infected propagules such as seeds, cuttings, tubers, bulbs, or sets. When these materials are planted, the pathogen is directly introduced to the new location. For instance, pathogens like Ralstonia solanacearum, causing bacterial wilt, are directly transmitted through infected potato tubers used for planting **(Dey et al. 2023).** Similarly, many seed-borne pathogens, including certain fungal and bacterial species, are directly transferred via contaminated seeds.
    b. Indirect transmission, in contrast, involves pathogen movement to new plants via an external agent or vector, separate from the planting material. These agents can be biotic, such as insects, animals, or other plants, or abiotic, like wind, water, or contaminated tools and equipment. Insects are particularly significant indirect vectors for numerous plant pathogens, including viruses, bacteria, and fungi **(West 2014; Kumar et al. 2022).** They can carry pathogens externally on their bodies or internally and transmit them while feeding or moving between plants. For example, wind dispersal is a crucial indirect transmission method for many fungal pathogens, such as rust fungi, enabling spore spread over considerable distances and leading to epidemics in cereal crops **(Aakash Goyal et al. 2010).**

Chapter-4
Classification of Plant Virus

Baltimore Classification System:

Baltimore classification was created in 1971 by virologist **'David Baltimore'** and initially only included the first six groups. It was later expanded to include group VII after the discovery of dsDNA-RT viruses. Since then, it has become common among virologists to use Baltimore classification alongside virus taxonomy due to its utility. In 2018 and 2019, Baltimore classification was partially integrated into virus taxonomy based on evidence that certain groups were descended from common ancestors.

- ❖ Groups plant viruses into seven classes based on genome and replication
  - Class I: dsDNA viruses (Caulimoviridae)
  - Class II: ssDNA viruses (Geminiviridae)
  - Class III: dsRNA viruses (Reoviridae)
  - Class IV: (+)ssRNA viruses (Potyviridae, Bromoviridae)
  - Class V: (-)ssRNA viruses (Rhabdoviridae)
  - Class VI: ssRNA-RT viruses (not found in plants)
  - Class VII: dsDNA-RT viruses (Caulimoviridae)
- ❖ System facilitates understanding of viral replication strategies
  - Provides insights into genome structure and expression mechanisms
  - Allows for comparison of viruses across different host types

Fiveable (2024)

Major plant virus families are:

- Geminiviridae
- Potyviridae
- Bromoviridae

Unique plant virus families are:

- Caulimoviridae
- Tombusviridae
- Closteroviridae
- Luteoviridae

Family: Geminiviridae (15 genera collectively containing 549 species)

The Gemini viruses are a family of small, non-enveloped viruses with genomes comprising **one or two single-stranded, circular DNAs** of 2.5–5.2 kb. Gemini viruses infect a wide range of plant species and are transmitted by various insects in four families of homopterans **(whiteflies, leafhoppers, aphids and treehoppers)**. Gemini viruses are important plant pathogens causing economically important diseases in most tropical and subtropical regions of the world.

Characteristics:

1. **Virion:** Twinned (geminate) incomplete icosahedra, T=1, 22×38 nm with a single coat protein.
2. **Genome:** 2.5–5.2 kb of single-stranded, circular DNA, mono- or bipartite.
3. **Replication:** Complementary strand synthesized in the nucleus by host replication factors; double-stranded circular molecules serve as templates for both transcription and replication; replication employs a rolling-circle mechanism and also a recombination-dependent mechanism.
4. **Translation:** From transcribed mRNAs; members of some genera use transcript splicing.
5. **Host range:** Plants (monocots and dicots).

Fiallo-Olivé *et al.*, (2021)

Morphology:

Virions are typically twinned ("geminate"). For maize streak virus (MSV, genus *Mastrevirus*), cryo-electron microscopy has shown that virions are about 22×38 nm in size, consisting of two incomplete icosahedra (T=1) containing a total of 110 coat protein subunits organized as 22 pentameric capsomers **(Zhang *et al,* 2001)** The structure of Ageratum yellow vein virus (genus *Begomovirus*) at 3.3 Å resolution has shown that the N-terminus of the single CP adopts three different conformations essential for building the interface between geminate halves **(Hesketh *et al,* 2018)**.

Physicochemical and physical properties:

Nucleic acid:

Twinned virions contain a single copy of circular ssDNA, ranging from 2.5 to 3.2 kb. Hence, for viruses with bipartite genomes, two virions containing different genomic components are required for infection, the total genome being about 5.2 kb **(Von Arnim *et al.*, 1993; Hamilton *et al.,* 1983)**. Half-size defective components and ssDNA satellites are also encapsulated **(Zhou, 2013)**.

Proteins:

Virions contain a single structural protein (CP; Mr about 28-34×10^3). No other proteins have been found associated with virions **(Zhang *et al*., 2001; Goodman *et al*., 1980)**.

Biology:

Members of the genus *Begomovirus* are transmitted by whiteflies, those of the genera *Mastrevirus*, *Curtovirus*, *Becurtovirus*, *Mulcrilevirus* and *Turncurtovirus* are transmitted by leafhoppers, those of the genus *Capulavirus* are transmitted by aphids, and members of species in the genera *Topocuvirus* and *Grablovirus* are transmitted by treehoppers. The vectors of members of the other genera remain unknown. Some viruses in the family *Geminiviridae* infect a wide range of plant species while others have a narrow host range.

Members of the genera *Becurtovirus, Begomovirus, Capulavirus, Citlodavirus, Curtovirus, Grablovirus, Mulcrilevirus, Opunvirus, Topilevirus, Topocuvirus* and *Turncurtovirus* infect dicot plants. However, most members of the genus *Mastrevirus*, the only member of the genus *Eragroviurs* and one of the three members of the genus *Maldovirus* infect monocot plants. Gemini viruses are important plant pathogens causing economically important diseases in most tropical and subtropical regions of the world **Fiallo-Olivé *et al.*, (2021)**.

Viruses classified into the 15 genera show distinct host ranges, insect vectors and genome organizations:

Becurtovirus, Capulavirus, Citlodavirus, Curtovirus, Eragrovirus, Grablovirus, Maldovirus, Mastrevirus, Mulcrilevirus, Opunvirus, Topilevirus, Topocuvirus, Turncurtovirus and *Begomovirus*.

Derivation of names:

- *Geminiviridae*: from Latin *geminus* meaning "twin", describing the characteristic twinned (geminate) particle morphology.
- *Becurtovirus*: from the species *Beet curly top Iran virus*.
- *Begomovirus*: from the species *Bean golden yellow mosaic virus* (previously *Bean golden mosaic virus*).
- *Capulavirus*: from the species Euphorbia caput-*medusae latent virus*.
- *Citlodavirus*: from the species *Citrus chlorotic dwarf associated virus*.
- *Curtovirus*: from the species *Beet curly top virus.*
- *Eragrovirus*: from the species *Eragrostis curvula streak virus.*
- *Grablovirus*: from the species *Grapevine red blotch virus.*
- *Maldovirus*: from the scientific name of the host plant *Malus domestica, and virus.*
- *Mastrevirus*: from the species *Maize streak virus.*
- *Mulcrilevirus*: from the species *Mulberry crinkle leaf virus.*
- *Opunvirus*: from the species *Opuntia virus 1.*
- *Topilevirus*: from the species *Tomato apical leaf curl virus.*

- *Topocuvirus*: from the species *Tomato pseudo-curly top virus.*
- *Turncurtovirus*: from the species *Turnip curly top virus.*

Genome organization and replication:

Viruses in the genera *Becurtovirus, Capulavirus, Citlodavirus, Curtovirus, Eragrovirus, Grablovirus, Maldovirus, Mastrevirus, Mulcrilevirus, Opunvirus, Topilevirus, Topocuvirus* and *Turncurtovirus* have a single genomic component, whereas those in the genus *Begomovirus* have either one or two components.

In the host plants, replication occurs through double-stranded replicative intermediates by both recombination-dependent and rolling circle mechanisms. One member of the genus *Begomovirus*, tomato yellow leaf curl virus, is replicated in the insect vector *Bemisia tabaci.*

Family- Potyviridae (13 genera including 259 species)

Members of the family *Potyviridae* (termed potyvirids) consist of monopartite and bipartite plant viruses with a single-stranded, positive-sense RNA genome and flexuous, filamentous particles. Genomes have a VPg covalently linked to the 5′-end, and, for most of them, the 3′-terminus is polyadenylated. Genomes encode a large polyprotein that is self-cleaved into a set of functional proteins, and another small protein produced from the genomic RNA as a *trans*-frame protein. Gene order is generally conserved throughout the family.

Characteristics:

1. **Virion**: Non-enveloped, flexuous and filamentous capsid, 650–950 nm long and 11– 20 nm in diameter with a single core capsid protein.
2. **Genome:** 8.2–11.5 kb of positive-sense, single-stranded, usually monopartite RNA (bipartite in genus *Bymovirus*).
3. **Replication:** Cytoplasmic replication in viral replication complexes residing in membranous 6K2-induced ER-derived vesicles.
4. **Translation:** Directly from genomic RNA.
5. **Host range:** Most members have a narrow natural host range, but can infect a wider range of experimental hosts, and a few members infect species in up to 30 plant families. Transmission to experimental hosts is readily accomplished by mechanical inoculation. Many viruses are widely distributed. Distribution is aided by seed transmission in some cases.

Morphology:

Virions are flexuous filaments with no envelope and are 11–20 nm in diameter, with a helical pitch of about 3.4–3.5 nm. Particle lengths of members of some of the twelve genera differ. Members of the genera *Arepavirus, Bevemovirus, Brambyvirus, Celavirus, Ipomovirus, Macluravirus, Poacevirus, Potyvirus, Roymovirus, Rymovirus* and *Tritimovirus* are monopartite with particle modal lengths of 650–950 nm. Members of the genus Bymovirus are bipartite with particles of two modal lengths of 250–300 nm and 500–600 nm.

Physicochemical and physical properties:

Virions of viruses in the genera *Potyvirus* and *Rymovirus* have a density in CsCl of about 1.31 g cm^{-3} and sedimentation coefficient $S_{20,w}$ of 137–160S. Those of the genus *Bymovirus* have a density in CsCl of about 1.29 g cm^{-3}.

Nucleic acid:

Viruses in all genera, except *Bymovirus*, have a single molecule of positive-sense, single-stranded (ss) RNA of 8.2 kb (bellflower veinal mottle virus-SW, genus *Bevemovirus*; artichoke latent virus-FR37, FR50, genus *Macluravirus*) to 11.5 kb (celery latent virus, genus *Celavirus*). Virions are infectious. A tract of 20 to 160 adenosine residues is present at the 3′-terminus, except for the *Celavirus* celery latent virus. *Bymovirus* have two positive-senses, ssRNA molecules; RNA1 is 7.3–7.6 kb and RNA2 is 3.5–3.7 kb. Both RNAs have 3′-terminal polyadenylate tracts and probably a VPg at their 5′-termini.

Proteins:

Virions contain one type of coat (capsid) protein (CP) of 28.5–47 kDa. N-terminal residues are positioned on the exterior of the Virion **(Zamora *et al.,* 2017, Cuesta *et al.,* 2019)**. Mild trypsin treatment removes N- and C-terminal segments, leaving a trypsin-resistant core of about 24 kDa. Plant proteases may degrade the CP in vivo, as occurs in vitro during purification using some procedures or from particular hosts. All potyviral CPs display significant a sequence identity in the trypsin-resistant core, but little identity in their N and C-terminal segments. A virus-encoded viral protein genome-linked (VPg) of about 24 kDa is covalently linked to the 5′-terminal nucleotide. The particles may also contain other virus-encoded proteins like the helper component protease (HC-Pro) (Torrance et al., 2006), or the cylindrical inclusion (CI) protein **(Gabrenaite-Verkhovskaya *et al.,* 2008)**, and the host factor elF4E **(Tavert-Roudet *et al.,* 2017)**.

Biology:

Potyvirids are vectored by a variety of organisms. Members of the genera *Potyvirus* and *Macluravirus* have aphid vectors that transmit in a non-persistent, non-circulative manner. Viruses in other genera in the family *Potyviridae* lacking these motifs are not transmitted by aphids, and include rymoviruses, poaceviruses and tritimoviruses which are transmitted by eriophyid mites in a semi-persistent manner. The vector of rose yellow mosaic virus (RoYMV, a member of Rose yellow mosaic virus, genus *Roymovirus*) has not been identified. *Bymoviruses* are transmitted by root-infecting plasmodiophorids. *Ipomoviruses* appear to be transmitted by whiteflies. The vector of members of the single species in the genera *Brambyvirus* and *Celavirus* are unknown. The vector of bellflower veinal mottle virus (BVMV), a member of the only species in the genus *Bevemovirus*, has not been identified.

Potyvirids can be mechanically transmitted to other hosts in experimental studies. Contact transmission of some potyviruses between adjacent plants may occur naturally **(Jones**

2018). Some viruses are seed borne, and some are pollen transmitted, such as zucchini yellow mosaic virus **(Harth *et al.*, 2017)**.

Transmission:

Potyvirids are vectored by a variety of organisms. Members of the genera *Potyvirus* and *Macluravirus* have aphid vectors that transmit in a non-persistent, non-circulative manner. Viruses in other genera in the family *Potyviridae* lacking these motifs are not transmitted by aphids, and include *rymoviruses, poaceviruses* and *tritimoviruses* which are transmitted by eriophyid mites in a semi-persistent manner. The vector of rose yellow mosaic virus (RoYMV, a member of Rose yellow mosaic virus, genus *Roymovirus*) has not been identified.

Bymovirus are transmitted by root-infecting plasmodiophorids. *Ipomovirus* appear to be transmitted by whiteflies. The vector of members of the single species in the genera *Brambyvirus* and *Celavirus* are unknown. The vector of bellflower veinal mottle virus (BVMV), a member of the only species in the genus *Bevemovirus*, has not been identified.

Potyvirids can be mechanically transmitted to other hosts in experimental studies. Contact transmission of some potyviruses between adjacent plants may occur naturally (**Jones 2018)**. Some viruses are seed borne, and some are pollen transmitted, such as zucchini yellow mosaic virus **(Harth *et al.*, 2017).**

Viruses classified into the 13 genera show distinct host ranges, insect vectors and genome organizations:

Members of the genera *Arepavirus, Bevemovirus, Brambyvirus, Celavirus, Ipomovirus, Macluravirus, Poacevirus, Potyvirus, Roymovirus, Rymovirus, Bymovirus* and *Tritimovirus*.

Derivation of names:

- *Arepavirus*: from areca palm necrotic spindle-spot virus.
- *Bevemovirus*: from bellflower veinal mottle virus.
- *Brambyvirus*: from bramble, the host of blackberry virus Y, a member of the species *Blackberry virus* Y.
- *Bymovirus*: from barley yellow mosaic virus.
- *Celavirus*: from celery latent virus.
- *Ipomovirus*: from *Ipomea*, the genus of sweet potato, and mosaic, the symptoms induced on the host of members of the species *Sweet potato mild mottle virus*.
- *Macluravirus*: from the genus name of the host (*Maclura*) of members of the species *Maclura* mosaic virus.
- *Poacevirus*: from Poaceae, the family name of the hosts of members of two species in the genus.
- *Potyviridae*, *Potyvirus*: from the species *Potato virus* Y, a member of the genus *Potyvirus*.
- *Roymovirus*: from rose yellow mosaic virus.

- *Rymovirus*: from ryegrass mosaic virus, a member of the species *Ryegrass mosaic virus*.
- *Tritimovirus*: from the host genus (*Triticum*) and induced symptoms (mosaic) of isolates of the species *Wheat streak mosaic virus*.

Family: Bromoviridae (06 genera, including 52 species)

The family *Bromoviridae* includes plant viruses with tri-segmented, positive-sense RNA genomes of about 8 kb. Genomic RNAs are packaged in separate virions that may also contain subgenomic, defective or satellite RNAs. Virions are variable in morphology (spherical or bacilliform) and are transmitted mechanically, in/on pollen, and non-persistently by insect vectors. Members of the family cause major disease epidemics in fruit, vegetable and fodder crops such as tomato, cucurbits, bananas, and alfalfa.

Characteristics:

1. **Virion:** Spherical or quasi-spherical (26–35 nm diameter) or bacilliform (18–26 nm diameter, 30–85 nm long).
2. **Genome:** Three segments of linear positive-sense single-stranded RNA, comprising about 8 kb in total.
3. **Replication:** On cytoplasmic membranes with genomic RNAs. Coat protein may be required for genome activation.
4. **Translation:** Directly from genomic or subgenomic RNAs.
5. **Host range:** From narrow to broad range of plants.

Morphology:

Virions are either spherical or quasi-spherical having *T=3* icosahedral symmetry, and a diameter of 26–35 nm (members of the genera *Anulavirus, Bromovirus, Cucumovirus* and *Ilarvirus*) or bacilliform (members of the genera *Alfamovirus, Ilarvirus* and *Oleavirus*) having (within members of a species) diameters of 18–26 nm and lengths of 30–85 nm, depending on the virus. Genomic RNAs are packaged in separate virions that may also contain subgenomic RNAs (sgRNAs), defective RNAs or satellite RNAs.

Nucleic acid:

Total genome length is approximately 8 kb. Genomes consist of three linear, positive-sense single-stranded (ss) RNAs with 5′-terminal cap structures. The 3′-termini are not polyadenylated, but generally are highly conserved within members of the same species or isolate, and form strong secondary structures. They are either tRNA-like and can be aminoacylated (members of the genera *Bromovirus* and *Cucumovirus*) or form other structures that are not aminoacylated (members of the genera *Alfamovirus, Anulavirus, Ilarvirus* and *Oleavirus*).

Proteins:

A single 20–24 kDa coat protein (CP) is expressed from a sgRNA. The CP is generally required for systemic movement and may be required for cell-to-cell spread in some cases. CP may also be required for virus expression and replication (members of the genus *Alfamovirus*) or activation of replication (members of the genus *Ilarvirus*). The phenomenon of genome activation has been demonstrated to cross group boundaries since the CP of an *alfamovirus* can activate the genome of an *ilarvirus* and vice versa. An intriguing feature of the *alfamovirus* CP is its accumulation in nucleus and nucleolus **(Herranz *et al.*, 2012).**

Lipids:

Lipids are not associated with virions.

Carbohydrates:

Carbohydrates are not associated with virions.

Biology:

The natural host range of the viruses spans from very narrow (members of the genera *Bromovirus, Oleavirus*) to extremely broad (members of the genus *Cucumovirus*). Members of the family cause major disease epidemics in fruit, vegetable and fodder crops such as tomato, cucurbits, bananas, and alfalfa. *Bromoviruses* are transmitted mechanically, in/on pollen, through seeds, and non-persistently by insect vectors.

Derivation of names:

- *Alfamovirus*: from alfalfa mosaic virus.
- *Anulavirus*: from Latin "*anularis*" (ring-shaped) describing the concentric symptom induced in tomato by members of the species *Pelargonium zonate spot virus*.
- *Bromoviridae*, *Bromovirus*: from Brome mosaic, also, from *Bromus* (genus of the host of brome mosaic virus).
- *Cucumovirus*: from *cucu*mber *mo*saic virus.
- Ilarvirus: from the disease symptom isometric labile ringspot.
- *Oleavirus*: from *Olea*, the genus name of olive, the host for members of the genus.

Family: Caulimoviridae (11 genera including 108 species)

Caulimoviridae is a family of non-enveloped reverse-transcribing plant viruses with non-covalently closed circular dsDNA genomes of 7.1–9.8 kbp that are encapsidated by viral coat proteins into isometric virions (members of the genera *Caulimovirus, Cavemovirus, Petuvirus, Rosadnavirus, Solendovirus* and *Soymovirus*) or bacilliform-shaped virions (members of the genera *Badnavirus and Tungrovirus*). No data is currently available on the virion morphology for viruses in the genera *Dioscovirus and Vaccinivirus*.

Members of the *Caulimoviridae* infect a wide range of monocot and dicot plants, although members of a single species have generally narrow host ranges. Some viruses of this family cause economically important diseases of tropical and subtropical crops. Insect vectors have been identified for *badnaviruses, caulimoviruses* and *tungroviruses*. Endogenous viral elements (EVEs; viral DNA integrated into the host nuclear genome) are known for *badnaviruses, caulimoviruses, cavemoviruses, petuviruses* and *solendoviruses*.

Characteristics:

1. **Virion:** Virions are either isometric or bacilliform with no envelop
2. **Genome:** Non-covalently closed circular dsDNA of 7.1–9.8 kbp with discontinuities in both strands.
3. **Replication:** Nuclear transcription by host DNA-directed RNA polymerase II, generates pregenomic (pg) RNA and, in members of some genera, sub genomic (sg) RNA. Replication is cytoplasmic via reverse transcription of pgRNA by viral reverse transcriptase.
4. **Translation:** From capped and polyadenylated pgRNA and, in members of some genera, sgRNA and spliced version(s) of pgRNA.
5. **Host range:** Plants (monocots and dicots).

Morphology:

Virions are either isometric or bacilliform depending on the genus. There is no envelope.

Physicochemical and physical properties:

Virions have buoyant densities in CsCl of 1.37 g cm^{-3} (members with isometric virions) or in Cs2SO4 of 1.31 g cm^{-3} (members with bacilliform virions). $S_{20,w}$ is in the range of 200 to 220 S. Virions are very stable between pH 4 and 9 and in high salt concentrations.

Nucleic acid:

Virions contain a single molecule of non-covalently closed circular dsDNA of 7.1–9.8 kbp. Each strand of the genome has discontinuities at specific sites (positions of the primers for reverse transcriptase): the negative-sense strand has one discontinuity (Met-tRNA primer binding site) and the positive-sense strand has between one and three discontinuities (purine-rich sequences resistant to RNase H).

Proteins:

Genomes contain between one and eight ORFs, depending on the genus. The virus-encoded proteins common to all viruses, regardless of the genus they belong to, are a movement protein (MP), a capsid protein (CP), a multipurpose virion-associated protein (VAP), an aspartic protease (AP) and a reverse transcriptase (RT) with tethered RNAse H1 enzyme.

Lipids: None.

Carbohydrates:

The capsid protein of cauliflower mosaic virus (CaMV) is glycosylated.

Biology:

Most viruses have a narrow host range; those in the genera *Caulimovirus, Cavemovirus, Petuvirus, Rosadnavirus, Solendovirus, Soymovirus* and *Vaccinivirus* are restricted to dicotyledonous plants; tungroviruses and dioscoviruses infect monocotyledonous plants and badnaviruses infect either mono- or dicots. Many members of the family are spread by vegetative propagation.

The geographic range of many caulimovirids is wide; members of most species in the genera *Badnavirus, Tungrovirus* and *Dioscovirus* are primarily tropical or subtropical with some of them being widespread in temperate and sub-Antarctic climates, whereas members of most species in the genera *Caulimovirus, Cavemovirus, Petuvirus, Rosadnavirus, Solendovirus, Soymovirus* and *Vaccinivirus* are found in temperate regions.

The symptoms caused by these viruses are variable and dependent on the virus, host and climatic conditions. Mosaic or vein clearing symptoms predominate amongst members of the genera *Caulimovirus, Cavemovirus, Petuvirus, Rosadnavirus, Solendovirus* and *Soymovirus* whereas interveinal chlorotic mottling, stunting, yellow-orange foliar discoloration and streaking are the most frequent symptoms associated with infections by viruses in the genera *Tungrovirus* and *Badnavirus*.

Derivation of names:

- *Badnavirus*: from bacilliform DNA viruses.
- *Caulimovirus*: from cauliflower mosaic virus.
- *Cavemovirus*: from cassava vein mottle virus.
- *Dioscovirus*: from Dioscorea, the genus containing *D. nummularia*, host to the type member.
- *Petuvirus*: from petunia vein clearing virus.
- *Rosadnavirus*: from Rosa DNA virus, where Rosa is the generic epithet of rose and DNA refers to the composition of the virus genome.
- *Ruflodivirus*: from Rudbeckia flowers distortion virus
- *Solendovirus*: from Solanaceae endogenous virus.

- *Soymovirus*: from soybean chlorotic mottle virus.
- *Tungrovirus*: from rice tungro bacilliform virus, tungro meaning 'degenerated growth' in a Filipino dialect.
- *Vaccinivirus*: from *Vaccinium*, the genus of the cultivated blueberry, host to the type member.

Teycheney *et al.*, (2020)

Family: Tombusviridae

Morphology:

Capsids exhibit T=3 icosahedral symmetry and are composed of 180 identical protein subunits in three conformationally distinct states. Capsids are formed with CP having one of two distinct phylogenetic origins. The virions from the genera *Aureusvirus, Avenavirus, Carmovirus, Dianthovirus* and *Tombusvirus* have a rounded outline, a granular surface and a diameter of about 32–35 nm. Each subunit folds into three distinct structural domains: R, the N-terminal internal domain interacting with RNA'S, the shell domain constituting the capsid backbone; and P, the protruding C-terminal domain, which gives the virus its granular appearance. P domains are clustered in pairs to form 90 projections. The S domain forms a beta barrel structure made up of eight β-strands. Two Ca2+ binding sites stabilize contacts between adjacent S domains of the A, B and C subunits at the pseudo three-fold axis. The capsids of viruses in the genera *Machlomovirus, Necrovirus* and *Panicovirus* are composed of similarly structured CPs that lack the P domain and thus have a smooth appearance. Particles range in diameter between 30–32 nm, and the S domain is related to the CPs of sobemoviruses.

Physicochemical and physical properties:

Virions sediment as one component with an $S_{20,w}$ of 118–140S, have a buoyant density ranging from 1.34 to 1.36 g cm^{-3} in CsCl, and a virion Mr of $8.2–8.9\times10^6$. Virions are stable at acidic pH, but expand above pH 7 and in the presence of EDTA. Virions are resistant to elevated temperatures (thermal inactivation usually occurs above 80 °C) and are insensitive to organic solvents and non-ionic detergents.

Nucleic acid:

With the exception of those of the genus *Dianthovirus*, virions contain a single molecule of positive sense, linear ssRNA, that constitutes about 17% of the particle weight, and have a size ranging from 3.7 to 4.8 kb, depending on the genus. *Dianthovirus* virions contain two genomic RNAs of approximately 3.8 kb and 1.4 kb. The 5'-end of the genome is uncapped. The 3'-ends are not polyadenylated. dsRNAs corresponding in size to viral genomic and sgRNAs are present in infected tissues. DI RNAs occur in some genera. In addition, some members have satellite RNAs or satellite viruses associated with them.

Proteins:

Capsids are composed of one of two phylogenetically distinct groups of CP subunit. In those genera that have a CP lacking a protruding domain, the CP subunit ranges in size from 25–30 kDa. In those genera with a CP containing a P domain, the CP subunit ranges in size from 37 to 48 kDa.

Lipids: None reported.

Carbohydrates: None reported.

Biological properties:

Host range:

The natural host range of individual virus species is relatively narrow. Members can either infect monocotyledonous or dicotyledonous plants, but no species can infect both. The experimental host range is wide. Infection is often limited to the root system, but when hosts are invaded systemically, viruses enter all tissues. Many members induce a necrosis symptom in the foliar parts of the plant. Diseases are characterized by mottling, crinkling, necrosis and deformation of foliage. Some infections are symptomless in their natural hosts.

Transmission:

All members are readily transmitted by mechanical inoculation and through plant material used for propagation. Some may be transmitted by contact and through seeds. Viruses are often found in natural environments, i.e. surface waters and soils from which they can be acquired without assistance of vectors. Transmission by the chytrid fungus in the genus *Olpidium* and by beetles has also been reported for members of several genera. Most members can be transmitted through the soil either dependent on, or independent of, a biological vector.

Derivation of names:

- *Aureus*: from the specific epithet of *Scindapsus aureus* (pothos), natural host of the virus.
- *Avena*: from *Avena*, the generic name for oats.
- *Carmo*: from *carnation* mottle.
- *Diantho*: from *Dianthus*, the generic name of carnation.
- *Machlomo*: from *maize chlorotic mottle*.
- *Necro*: from Greek *nekros*, “dead body”.
- *Panico*: from *panicum mosaic*.
- *Tombus:* from *tomato bushy stunt.*

Family: Closteroviridae (7 genera, and 58 species)

Plant viruses in the family *Closteroviridae* possess long, helically constructed filamentous particles (650–2,200 nm in length) and a large positive-sense single-stranded, mono, bi- or tripartite RNA genome (13,000 to nearly 19,000 nucleotides). The presence of a cellular

HSP70 homolog and a duplicated, diverged copy of the capsid protein (minor capsid protein, CPm) genes in the virus genome are hallmarks of the family. The genome expression strategy is based on proteolytic processing, a +1 ribosomal frameshift, and sub-genomic messenger RNAs.

Members of the family are classified into four genera: *Ampelovirus, Closterovirus, Crinivirus* and *Velarivirus*. Their genetic diversity is primarily influenced by strong negative selection and recombination. Viruses are mostly phloem-restricted and induce specific cytoplasmic aggregates of virus particles intermingled with membranous vesicles derived from the endoplasmic reticulum and possibly mitochondria.

Characteristics:

1. **Virion:** Non-enveloped, flexible filaments of 650–2200 nm in length and 12 nm in diameter.
2. **Genome:** 13–19.3 kb of positive-sense, mono-, bi- or tripartite RNA.
3. **Replication:** In association with vesicular membranes derived from the endoplasmic reticulum and mitochondria.
4. **Translation:** Proteolytic processing, a +1 ribosomal frameshift, and sub-genomic messenger RNAs.
5. **Host range:** Plants (mainly dicots), transmitted by **aphids, whiteflies, mealybugs and soft scales. No seed transmission.**

Morphology:

Virions are helically constructed filaments with a pitch of the primary helix in the range of 3.4–3.8 nm, containing about 10 protein subunits per turn of the helix and showing a central hole of 3–4 nm. The very flexuous and open structure of the particles is the most conspicuous trait of members of the family **(Agranovsky, 2016)**. Virions have a diameter of about 12 nm and lengths ranging from 650 nm (viruses with a fragmented genome) to over 2200 nm (viruses with a monopartite genome).

The fragility of virions and a tendency to end-to-end aggregation contribute to the fact that many viruses are reported with a range of lengths. Two types of coat proteins (CP), the major CP and a CP analog or minor CP (CPm), are the most abundant protein components involved in the formation of (most) closterovirid particles. CPm encapsidates the 600–700 5′-terminal nucleotides of the virus RNA, at one extremity (75–100 nm) of the particle, as shown for beet yellows virus (BYV), carrot yellow leaf virus (CYLV), citrus tristeza virus (CTV), grapevine leaf roll-associated virus 2 (GLRaV-2) and lettuce infectious yellows virus (LIYV), thus forming a distinct structure for which the terms “rattlesnake”, “heterodimeric” or “bipolar” have been coined **(Agranovsky, 2016)**.

Physicochemical and physical properties:

Virions are usually sediment as a single band in sucrose or Cs_2SO_4 gradients. $S_{20,w}$ is around 130–140, buoyant density is 1.33 g cm^{-3} in CsCl and 1.257 g cm^{-3} in Cs_2SO_4. Virions of several members are degraded by CsCl and are unstable in high salt concentration, resist

moderately high temperatures (thermal inactivation is around 45–55 °C) and organic solvents, but are sensitive to RNase and chelation.

Nucleic acid:

Regardless of whether the genome is monopartite or fragmented, virions contain a single molecule of linear, positive-sense, single-stranded RNA, constituting 5–6% of the particle weight. Genome size is related to particle length, ranging from 13,000 to slightly over 19000 nucleotides. The 5′-end of the genome is likely capped. The 3′-end is not polyadenylated and does not possess a tRNA-like structure, but has several hairpin structures and a putative pseudoknot essential for replication **(Agranovsky, 2016)**.

Proteins:

Structural proteins of most members of the family consist of a major CP and a diverged copy of it, denoted minor CP (CPm), with masses ranging from 22 to 46 kDa (CP) and 23 to 80 kDa (CPm), according to species. A group of ampeloviruses with a small genome (about 13,000 nt) apparently lack a true CPm. For BYV, and presumably for most other members of the family, CPm is required for the assembly of the 5′-extremity of the virion, and the ~60 kDa protein (p55-p64) is required for incorporation of both the 70 kDa heat shock protein homolog (HSP70h) and the CPm into virions, which also incorporate a 20 kDa protein (p20) that may form the tip segment of the virion head **(Agranovsky, 2016)**.

Lipids: None reported.

Carbohydrates: None reported.

Biology:

The natural and experimental host ranges of individual viruses are usually restricted, except for a few members of the genus *Crinivirus*. Disease symptoms are of the discoloration type (i.e. yellowing or reddening of the leaves, small and late ripening fruit), as well as stunting, rolling, pitting and/or grooving of the woody cylinder of woody hosts. Infection is systemic, but usually limited to the phloem, which may necrotize to a varying extent. Members of a few species of the genus *Closterovirus* are transmissible by mechanical inoculation, though with difficulty, but no members of the genera *Ampelovirus, Crinivirus* and *Velarivirus* are mechanically transmissible. In vegetatively propagated crops, long-distance virus dissemination is primarily through infected propagating material. Members of some species can be transmitted through dodder (*Cuscuta* spp.).

Transmission:

Transmission is by **aphids, whiteflies, mealybugs** or soft scale insects in a semi-persistent manner. Experimental transmission by mechanical inoculation is very difficult or impossible, and seed transmission is not known. A few members in the family have been engineered as gene expression and RNA interference vectors.

Derivation of names:

- *Ampelo*: from Greek *ampelos*, meaning grapevine, the host of members of the type species of the genus *Ampelovirus*.
- *Clostero*: from Greek *kloster*, meaning spindle or thread.
- *Crini*: from Latin *crinis*, meaning hair, from the appearance of the very long thread-like particles.
- *Velari*: from Latin *velare*, meaning cryptic or veiled, because members of the type species of the genus *Velarivirus* do not cause any apparent disease symptoms upon infection of their natural host.

Chapter-5
Transmission of plant viruses by Aphids

Aphids (Aphididae, 192 species, 275 viruses)
Taxonomic classification:
Phylum: Arthropoda
Class: Insecta
Order: Hemiptera
Family: Aphididae
Genus: *Aphis, Myzus*
Species: *gossypii, craccivora, persicae*

The majority of viruses infecting plants are spread by insects, Hemipterans are by far the most important virus vectors, comprising more than 70% of all known insect-borne viruses. Among these, aphids and whiteflies are the major vectors of plant viruses transmitting more than 500 virus species. Among these, aphids (Aphididae, 192 species, 275 viruses) account for the transmission of 50% of the insect-vectored viruses **(Brunt *et al.,* 1996)**. The aphid transmitted viruses, including 8 families, 18 genera, and taxonomically unassigned viruses. **(James and Perry, 2004)**

Aphids are sap sucking insects and have piercing, sucking mouthparts. Their mouthparts include needle-like stylets that allow the aphid to access and feed on the contents of plant cells. On the other hand, there are several aphid species, such as *Myzus persicae*, that have as many as 50 primary and alternate species of host plants. Both acquisition and transmission of virus by aphids are affected by temperature, humidity and light. **(Agrios, 1997)**

More than half of the plant viruses, numbering more than 400, are transmitted from diseased to healthy plants by insects. Aphids also have good sense ability for the visual cues that enables them to locate their host as compared to other members of the homopteran family **(Kring, 1972)**

A number of unique features contribute to the success of aphids as vectors of plant viruses. These include:

(i) A polyphagous nature for some aphid species (e.g. *Myzus persicae*) that allows them to feed on a wide range of plant hosts, a property important for the dissemination of viruses that infect a large number of plant species;
(ii) The ability to undergo parthenogenetic reproduction, thus facilitating the rapid production of large quantities of offspring; and

(iii) The possession of a needle-like stylet capable of piercing plant cell walls and delivering viruses into a host cell. Feeding behaviour and host plant selection by an aphid will affect its potential as a vector. (**Harris and Maramarosch, 1977)**

Morphological identification:

Aphids have mouthparts that consist of two pairs of flexible stylets held within a groove of the labium. During feeding, the stylets are extended from the labium and, through a drop of gelling saliva; the stylets rapidly penetrate the epidermis. Penetration may stop at the epidermis or it may continue into the middle layers of leaf cells with a sheath of saliva forming around the stylets. The stylets move between the cells until they reach and enter a phloem sieve tube from which the aphids obtain their food.

Nature of damage:

Aphids cause damage through two primary mechanisms: direct damage from feeding and indirect damage by transmitting viral diseases. Aphids use their piercing-sucking mouthparts to feed on plant sap, which can weaken the plant, stunt growth, and potentially reduce yield. Aphids excrete **honeydew**, a sticky substance that can attract other pests and promote the growth of **sooty mold**, further impacting plant health.

Virus species transmitted by Aphids:

Eight genera of the plant viruses' viz. *Potyvirus* (Poty, sigla from *Potato Y*), *Macluravirus, Babuvirus, Bymovirus, Luteovirus* (Luteo, from Latin *luteus*, meaning yellow), *Cucumovirus* (Cucumo, sigla from *cucu*mber *mo*saic), *Comovirus, and Closterovirus* (Clostero, from Greek *Kloster,* meaning Thread),*Polerovirus, Umbravirus, Nanovirus* are transmitted by aphids in India. All ***potyviruses*** (the largest group of plant viruses) are transmitted by aphids followed by macluraviruses, babuviruses and luteoviruses.

Aphid-transmitted plant virus species from different families organized by their modes of transmission

Genus (Family)	Mode of transmission	No of aphid species
Alfamovirus (Bromoviridae)	Non circulative, Non persistent	1
Carlavirus (Unassigned)	Non circulative, Non persistent	31
Closterovirus (Closteroviridae)	Non circulative, Semi persistent	8
Caulimovirus (Caulimoviridae)	Non circulative, Semi persistent	9
Cucumovirus (Bromoviridae)	Non circulative, Non-persistent	3
Fabavirus (secoviridae)	Non circulative, Non persistent	4

Luteovirus (Luteoviridae)	Circulative, Non propagative	2
Macluravirus (Potyviridae)	Non circulative, Non persistent	2
Nanovirus (Unassigned)	Circulative, Non propagative	4
Polerovirus (Luteoviridae)	Circulative, Non propagative	5
Potyvirus (Potyviridae)	Non circulative, Non persistent	91
Umbravirus (Luteoviridae)	Circulative, Non propagative	7

(Ng and Perry, 2004)

Important Species of Aphids

Among all the species, following species of aphids are more feasible for transmission of plant viruses.

Myzus persicae followed by *Aphis gossypii* and *Aphis craccivora* are the most widely utilised aphid species for vector-virus study in India. *Myzus persicae* transmits about 16 plant viruses in different agriculturally important crops. Whereas, out of 15 species and 12 plant viruses transmitted by Aphis *gossypii* and *Aphis craccivora* respectively are available.

1. ***Aphis gossypii***- The cotton aphid (*Aphis gossypii*) is a serious pest in cotton cultivation worldwide and is commonly called melon or cotton aphid due to its preference for feeding on these crops. This species is economically important because it causes damage to crops by feeding on plant sap and by transmitting plant viruses. The cotton aphid causes yield losses in cotton crops, with severe infestations causing stunted growth, leaf curling, and the yellowing or wilting of leaves, leading to a reduction in photosynthesis and reduced yield. Moreover, aphids excrete honeydew, which encourages the growth of sooty mould, a fungal disease that obstructs photosynthesis and reduces plant vigour. In addition to causing reductions in yield, cotton aphids can transmit multiple viral diseases and experimentally recorded 20–24% transmission of the virus. This transmits 15 plant viruses and which can result in further economic losses. Cotton aphids have a worldwide distribution and are found in most cotton growing regions. However, environmental factors, such as temperature, humidity, and host availability, can affect their population dynamics and distribution. **(Jamin Ali, 2024)**



2. ***Myzus persicae*** – The Green peach aphid is a common pest known for its diverse range of hosts, which includes a variety of crops such as potato, peach, tomato, pepper, and other vegetables, herbs, and fruits. The small size, fast reproduction rate, and ability to transmit viral plant diseases make the peach-potato aphid an economically important pest in agriculture. Damage caused by the peach-potato aphid includes stunted growth, wilting, the yellowing and distortion of leaves, decreased photosynthesis, and reduced yields. This pest is considered among the most destructive aphids globally and has been reported to cause losses, ranging from 10% to 80%, in potato and other crops. (It transmits max number of viral diseases. It transmits about 16 plant viruses in different agriculturally important crops. This recorded 20–25% transmission of the virus. **(Jamin Ali, 2024)**



3. ***Aphis craccivora***- It is variously known as the cowpea aphid, groundnut aphid or black legume aphid, this cosmopolitan distribution and particularly well distributed in tropics. In early stage of infection adult aphids have no wings but as they crowded, winged forms appear in subsequent generations and disperse to other plants. This transmits 12 plant viruses and records 14-16% transmission of plant viruses. They vector a virus which causes mosaic like symptoms and results in yield loss. Young and adult cowpea aphid feed by sucking plant juices. They are found primarily on the growing points of the host plant including tips, flowers and developing bean pods. **(Schreiner, 2000)**



Transmission mechanisms

Insect vectors that have sucking mouthparts carry plant viruses on their stylets, and such viruses are known as stylet-borne, externally borne, or non-circulative, because they do not pass to the vector's interior.

Stylet-borne non-persistent transmission

Among the aphid-vectored plant viruses, a majority are transmitted in a noncirculative manner. These viruses are described as nonpersistent or semipersistent, depending on the length of time that an aphid remains viruliferous following feeding on an infected plant. If the aphid moults, virus is lost (does not 'persist') **(Agrios, 1997).**

In the few seconds in whom aphids acquire the virus, the aphid stylet usually penetrates only the epidermal cell. Actually, deeper penetration of the stylet into leaf tissues reduces the ability of aphids to transmit the virus.

Most externally borne viruses can be transmitted in the typical **stylet-borne non-persistent** manner. Nonpersistent virus transmission is characterized by very short acquisition and inoculation times of seconds to minutes **(Pirone and Perry, 2002)**. The insect can transmit the virus immediately after the acquisition feeding, that is, without any incubation period required for transmission. The insect retains the virus and is usually able to transmit it for only a few minutes after it acquired it.

Most of the nearly 300 known aphid borne plant viruses are stylet-borne nonpersistent. Some of the most important groups of plant viruses, such as those in the genera ***Potyvirus, Cucumovirus, Alfamovirus*****,** and the ***Caulimovirus*** transmitted by *Myzus persicae* are **stylet-borne non-persistent viruses.**

The virus encodes a non-structural protein which interacts with the aphid virus retention binding site and forms a bridge between the virus and the aphid stylet. However viruses are bound to the aphid stylet, there must also be a mechanism for release of the virus when the aphid feeds on the next plant. It appears that saliva alone may carry out this function.

Semi-persistent viruses –

Some externally borne non-persistent viruses are known as semi-persistent because they reach but do not seem to go past the foregut of the vector; As with the non-persistently transmitted viruses, acquisition can occur within minutes, but the efficiency increases with prolonged feeding **(Palacios *et al*., 2002)** and the second distinguishing feature of semi persistent transmission of vector can then retain (retention time) and transmit the virus to healthy plants for several hours.

Semi-persistent viruses are also assisted in their transmission by a transmission helper protein or coat protein configuration. The best known semi-persistent viruses are ***Caulimo viruses,*** which occur in most cell types and the ***Clostero viruses*** beet yellows virus and curly top virus, which are found primarily in phloem cells. In several of the semi-persistent viruses, a helper component seems to be involved in their transmission.

Persistent

Persistent transmission can be circulative or propagative depending on whether virus replicates inside insect vector. The vector requires several hours to a few days for acquisition of persistently transmitted viruses. Once acquired, a vector typically remains viruliferous for lifetime. Following the acquisition of non-persistently transmitted potyviruses, the aphid remains viruliferous only for a few feeding probes **(Bradley and Rideout, 1953)**

Persistent viruses are generally transmitted by one or a few species of aphids and cause symptoms characterized by leaf yellowing and leaf rolling.

List of aphids transmitting plant viruses

Disease	Causal organism	Vector
Alfalfa mosaic	Alfalfa mosaic virus (AMV)	*Myzus persicae,* *Aphis craccivora,* *Aphis gossypii* *Acyrthosiphon pisum*
Banana bract mosaic	Banana bract mosaic virus (BBrMV)	*Aphis gossypii* *Aphis craccivora* *Pentalonia nigronervosa* *Rhopalosipum maidis*
Banana bunchy top	Banana virus 1 (OR) Musa virus 1	*Pentalonia nigronervosa*
Banana mosaic	Cucumber mosaic virus (CMV)	*Myzus persicae* *Aphis gossypii*
Barley yellow dwarf	Barley yellow dwarf virus (BYDV)	*Rhopalosiphum maidis* *Sitobion avenae* *Rhopalosiphum padi*
Bean common mosaic	Bean common mosaic virus (BCMV)	*Myzus persicae* *Aphis fabae* *Aphis gossypii* *Aphis craccivora* *Lipaphis erysimi*
Bean yellow mosaic	Bean yellow mosaic virus (BYMV)	*Acyrthosiphon pisum*
Beet western yellows	Beet western yellows virus (BWYV)	*Myzus persicae*
Cabbage black ring spot	Turnip ring spot virus (TuMV) **(formerly called Cabbage black ring spot virus)**	*Myzus persicae*
Cardamom vein clearing (Kokke kandu)	Cardamom vein clearing virus (CdVCV)	*Pentalonia caladii*
Cauliflower mosaic	Cauliflower mosaic virus (CaMV)	*Myzus persicae*
Chilli mosaic	Tobacco mosaic virus (TMV)	*Myzus persicae* *Aphis gossypii*
Citrus tristeza	Citrus tristeza virus (CTV)	*Toxoptera citricida* *Toxoptera aurantii* *Aphis gossypii* *Myzus persicae* *Aphis craccivora Dactynotus jaceae* *Aphis craccivora* *Macrosiphum compositae*
Cowpea mosaic	Cowpea mosaic virus (CPMV)	*Aphis craccivora* *Myzus persicae*

		Aphis gossypii
Cucumber mosaic disease	cucumber mosaic virus (CMV)	*Myzus persicae*
Dahlia mosaic	Dahlia mosaic virus (DMV)	*Myzus persicae* *Aphis gossypii*
Garlic mosaic	Leek yellow stripe virus (LYSV)	*Myzus persicae* *Aphis craccivora*
Grassy shoot of sugarcane	Candidatus phytoplasma sacchari	*Rhopalosiphum maidis* *Melanaphis sacchari* *Melanaphis idiosacchari*
Katte disease of cardamom	Cardamom mosaic virus (CdMV)	*Pentalonia nigronervosa*
Lettuce mosaic	Lettuce mosaic virus (LMV)	*Myzus persicae* *Aphis gossypii* *Macrosiphum euphorbiae*
Onion yellow dwarf	Onion yellow dwarf virus (OYDV)	*Myzus persicae* *Aphis gossypii* *Aphis craccivora*
Papaya mosaic	Papaya mosaic virus (PapMV)	*Myzus persicae* *Aphis gossypii* *Aphis craccivora*
Papaya ring spot virus	Papaya ring spot virus-type P (PRSV-P)	*Myzus persicae* *Aphis gossypii* *Aphis craccivora* *Myzus nicotianae*
Pea enation mosaic	Pea enation mosaic virus (PEMV)	*Acyrthosiphon pisum*
Peanut green mosaic	Peanut green mosaic virus (PeGMV)	*Aphis craccivora* *Aphis gossypii* *Myzus persicae* *Toxoptera odinae*
Peanut mottle	Peanut mottle virus (PeMoV)	*Aphis craccivora* *Aphis gossypii* *Myzus persicae* *Rhopalosiphum padi*
Peanut rosette/ groundnut rosette	Peanut rosette virus (GRV)	*Aphis craccivora*
Peanut stripe	Peanut stripe virus (PStV)	*Aphis craccivora* *Aphis gossypii* *Myzus persicae*
Peanut stunt	Peanut stunt virus (PSV)	*Aphis craccivora* *Aphis spiraecola* *Myzus persicae*

Potato crickle	potato virus A	*Myzus persicae*
Potato leaf roll	potato virus A	*Myzus persicae*
Potato virus Y	Potato virus Y	*Myzus persicae* *Aphis gossypii*
Ragi mosaic	Ragi mosaic virus	*Rhopalosiphum maidis*
Rugose mosaic of potato	potato virus X and potato virus Y	*Myzus persicae*
Soybean mild mosaic	Soybean mild mosaic virus	*Myzus persicae*
Soybean mosaic	Soybean mosaic virus (SMV)	*Aphis glycines* *Acyrthosiphon pisum*
Sugarcane mosaic disease	Sugarcane mosaic virus (SCMV)	*Myzus persicae* *Aphis maydis* *Rhopalosiphum maidis* *Melanaphis sacchari* *Toxoptera graminum* *Hysteroneura setariae* *Longiunguis sacchari*
Sunflower mosaic	Sunflower mosaic virus (SMV)	*Myzus persicae* *Aphis gossypii* *Aphis craccivora*
Tobacco mosaic	Tobacco mosaic virus (TMV)	*Myzus persicae*
Turnip mosaic	Turnip mosaic virus (TuMV)	*Myzus persicae* *Brevicoryne brassicae* *Lipaphis erysimi*
Yellow leaf in sugarcane	Sugarcane yellow leaf virus (SCYLV)	*Melanaphis sacchari*

Note: Generally phytoplasma like organisms are transmitted by leaf hoppers but in case of grassy shoot of sugarcane are transmitted by Aphids

Chapter -6
Transmission of plant viruses by Whiteflies

Whiteflies (Aleyrodidae, 3 species, 43 viruses)
Taxonomic classification:
Phylum: Arthropoda
Class: Insecta
Order: Hemiptera
Family: Aleyrodidae
Genus: *Bemisia*
Species: *tabaci*

Of the approximately 1,500 species of whiteflies **(Martin, 2004),** only a few have been shown to vector plant viruses, including some species of the *Bemisia tabaci* complex and *Trialeurodes vaporariorum* **(Navas-Castillo *et al.* 2011)**

Morphological identification:

Whiteflies/snow flies are tiny, approximately 1 to 3 mm long, sap-sucking, soft-bodied winged insects commonly found in clusters on the under surface of the leaves **(Liu *et al*. 2007)**. They are so named as their entire body including wings is covered with white waxy powder. Whitefly adults are winged but only the first instar among the larvae is mobile. Whiteflies produce many generations in a year and reach high populations. Adults of these whiteflies resemble small moths, while the nymphs look more like a scale insect with a flattened oval shape. **(Soumia *et al*., 2020)**. Whitefly mouthparts and feeding behaviour resemble those of aphids.

Whitefly goes through six stages, namely egg, first, second, third and fourth larval stage (often referred to as 'pupa' although strictly spoken this is not true) and adult. The larvae are found on the underside of young leaves and have an oval shape. The first instar larvae (crawlers) are mobile, whereas the rest of the larvae stadia remain flattened on the leaf. The fourth larva stadium develops into a white, oval case encircled by a ring of erect waxy rods. This is called the pupa stadium and these pupae are found on the oldest leaves.
The adult emerges from the pupa via a T-shaped fissure. The adult whiteflies can usually be found in the top of the plant and on the underside of young leaves, where they deposit their eggs. When shaking infested plants, adults will first fly, then return to the underside of the leaves.

Nature of damage:

Both nymphs and adult stages of whitefly have piercing and sucking mouthparts and usually penetrate the phloem and suck the sap by inserting their stylets into the leaf and reducing plant vigor. Whiteflies also excrete honeydew, which promotes sooty mold that interferes with

photosynthesis. During this feeding process, they acquire plant viruses. Adult whiteflies may disperse and transmit the virus to new plants at subsequent feeding. They also secrete honeydew, a sticky substance on which saprophytic sooty mould develops and thereby hinders the photosynthetic efficiency of the plant**. (Soumia *et al*., 2020)**

Virus species transmitted by whiteflies:

Several genera of these whitefly-transmitted plant viruses *Begomovirus* (Geminiviridae), *Carlavirus* (Betaflexiviridae), *Crinivirus* (Closteroviridae), *Ipomovirus* (Potyviridae), *Torradovirus* (Secoviridae) include several hundred species of emerging and economically significant pathogens of important food and fibre crops (**Navas *et al.*, 2011).** Another unexpected case has been reported recently: the *polerovirus* (Luteoviridae) pepper whitefly-borne vein yellows virus (PeWBVYV) has been shown to be transmitted by whiteflies, an exception in the whole family Luteoviridae, whose members are typically transmitted by aphids (**Ghosh *et al.* 2019).**

Among all viruses transmitted by the whiteflies, begomoviruses to achieve successful transmission, About 90% *Begomoviruses* are transmitted by *Bemisia tabaci* whiteflies, while the *criniviruses* are about 6% and the whitefly transmitted *closteroviruses* are about 4% vectored by the whiteflies *Trialeuroides vaporariorum, T. abutilonea, B. tabaci*, and the **type B** of *B. tabaci* (also referred to as *B. argentifolii*).

They need to cross the midgut wall to reach the haemolymph and then accumulate in the primary salivary glands, from where they are secreted in the saliva to infect new plants **(Czosnek *et al*. 2017).**

Plant virus groups transmitted by whiteflies

Genus (Family)	Mode of transmission	Whitefly species
Begomovirus (Geminiviridae)	Circulative	*Bemisia tabaci* *Trialeurodes ricini* *T. vaporariorum*
Crinivirus (Closteroviridae)	Semipersistent	*B. tabaci* *T. vaporariorum* *T. abutiloneus* *B. afer sensu lato*
Torradovirus (Secoviridae)	Semipersistent	*B. tabaci* *T. vaporariorum*
Ipomovirus (Potyviridae)	Semipersistent	*B. tabaci* *A. dispersus* *T. vaporariorum*
Carlavirus (Betaflexiviridae)	Nonpersistent	*B. tabaci*
Polerovirus (Luteoviridae)	Unknown	*B. tabaci*

(Fiallo-Olive, 2019)

Important species are-

Only a few species of whiteflies transmit viruses, mostly in the tropics and subtropics, but the viruses they transmit cause very severe diseases. Out of the total reported whiteflies species *Bemisia* and *Trialeurodes* genera are virus vectors. In the genus *Bemisia*, only *Bemisia tabaci* (Gennadius) has been shown to be a vector whereas in the *Trialeurodes* genus, *Trialeurodes vaporariorum* (Westwood), *T. abutiloneus* (Haldeman) and *T. ricini* (Misra) transmit viruses **(Jones, 2007)**

1. ***Bemisia tabaci***



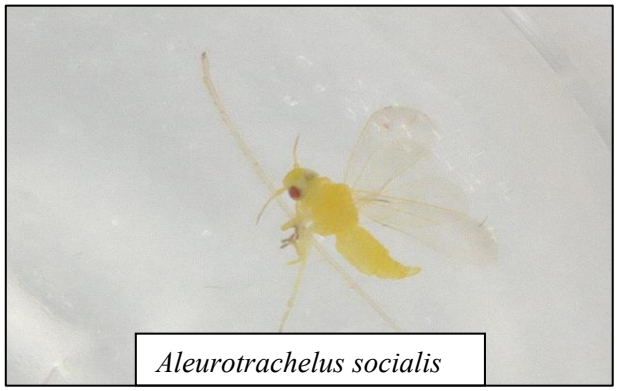
Whitefly, *Bemisia tabaci* (Hemiptera: Aleurodidae) a complex of morphologically indistinguishable species, and are transmits maximum number of plant viruses among whitefly species. **(Polston and Capobianco, 2013).** *Bemisia tabaci* (Gennadius) feeds on more than 600 host plants and vectors over 111 plant virus species and is considered to be a major invasive species worldwide. *Bemisia tabaci* damages crops by feeding on phloem sap and the large amounts of sticky honeydew produced can lower the rate of leaf photosynthesis. **(Powell *et al*, 2012)**

B. tabaci is a destructive pest of horticultural crops and ornamental plants worldwide **(Brown *et al.,* 1995)** especially because of its role as a vector of plant viruses **(Hogenhout *et al.,* 2008).** Actually, *B. tabaci* is a species complex containing at least 28 morphologically indistinguishable species.

2. *Bemisia gossypiperda*

It is also known as the cotton whitefly or the sweet potato whitefly. It is a complex and highly variable species with small, winged insect that feeds on plant sap, causing damage to plants and transmitting viruses in the process. Some common hosts of *Bemisia gossypiperda* include Cotton, Tomato, Papaya, Sweet potato and other ornamental and vegetable crops

3. *Aleurotrachelus socialis*


Aleurotrachelus socialis

It is the most damaging whitefly species on cassava. This can reduce yields by 60-80% **(Bellotti *et al.*, 1983).** These considerable yield losses during whitefly population outbreaks are due to direct feeding damage and the spread of plant pathogenic viruses. *A. socialis* extracts sap from the phloem of the leaves, causing leaf yellowing, chlorosis, curling, necrosis and abscission. Direct feeding acts in concert with the secretion of honeydew and subsequent sooty mould growth to reduce photosynthetic efficiency and reduce root yield.

Mode of transmission

The *begomoviruses* comprise an emerging and economically important group of plant viruses exclusively transmitted by the *B. tabaci* in many regions of the world. Begomoviruses is one of the largest and economically important groups of emerging insect vector. Begomoviruses are exclusively vectored by *B. tabaci* in a **persistent circulative manner. Rosen *et al.*, (2015)**

Whitefly instar nymphs and adults feed by inserting their proboscises into the leaf, penetrating the phloem and withdrawing sap. It is during this feeding process that plant viruses are acquired. Adult whiteflies may disperse and transmit the virus to new plants while feeding.

Begomoviruses are bipartite geminiviruses (Consists of Two circular SS-DNA molecules) and are transmitted by whiteflies in the **persistent circulative manner**. A helper factor coded by the virus seems to be involved in the transmission. The whitefly-transmitted monopartite closteroviruses and the bipartite criniviruses reach only the foregut of the vector and are transmitted in the **semi-persistent manner**. These viruses are retained in the vector for about 3-9 days. Two capsid proteins help the virus in its transmission by the vector.

Mutualism relationships between plant viruses and their insect vectors have been observed in some Hemipterans. In the case of *B. tabaci* biotype B and tomato yellow leaf curl China virus (TYLCCNV) interactions, **Jiu *et al.*, (2007)** found that fecundity, longevity and population density of whiteflies on virus infected tobacco plants increased.

List of diseases transmitted through Whiteflies

Disease	Causal organism	Vector
Beet pseudo-yellows	Beet pseudo-yellows virus (BPYV)	*Trialeuroides vaporariorum*
Cassava mosaic virus	Cassava mosaic virus (CMV)	*Bemisia tabaci*
Cotton leaf crumple	Cotton leaf crumple virus (CLCrV)	*Bemisia tabaci*
Cotton yellow mosaic	Cotton yellow mosaic virus (CYMV)	*Bemisia tabaci*
Curly shoot disease of French bean/ leaf curl of french bean	Tobacco curly shoot virus (TbCSV)	*Bemisia tabaci*

Dolichos yellow mosaic	Dolichos yellow mosaic virus (DoYMV)	*Bemisia tabaci*
Leaf curl of brinjal	Tomato leaf curl joydebpur virus (ToLCJoV)	*Bemisia tabaci*
Leaf curl of cabbage	Cabbage leaf curl virus (CaLCuV)	*Bemisia tabaci*
Leaf curl of Chilli	Chilli leaf curl virus (ChiLCV)	*Bemisia tabaci*
Leaf curl of cotton	Cotton leaf curl virus (CLCuV)	*Bemisia tabaci*
Leaf curl of cucurbit	Cucurbit leaf curl virus (CLCV)	*Bemisia tabaci*
Leaf curl of french bean/ curly shoot of French bean	French bean leaf curl virus (FbLCV)	*Bemisia tabaci*
Leaf curl of melon	Squash leaf curl virus (SLCV)	*Bemisia tabaci*
Leaf curl of okra	Okra leaf curl virus (OLCV)	*Bemisia tabaci*
Leaf curl of papaya	Papaya leaf curl virus (PaLCuV)	*Bemisia tabaci*
Leaf curl of pepper	Pepper leaf curl virus (PepLCV)	*Bemisia tabaci*
Leaf curl of radish	Radish leaf curl virus (RaLCV)	*Bemisia tabaci*
Leaf curl of sesame	Sesame leaf curl virus (SeLCV)	*Bemisia tabaci*
Leaf curl of sweet potato	Sweet potato leaf curl virus (SPLCV)	*Bemisia tabaci*
Leaf curl of squash	Squash leaf curl virus (SLCV)	*Bemisia tabaci*
Leaf curl of Tobacco	Tobacco leaf curl virus (TLCV)	*Bemisia tabaci*
Leaf curl of Tomato	Tomato yellow leaf curl virus (TYLCV)	*Bemisia tabaci*
Okra enation leaf curl disease	Okra enation leaf curl virus (OELCuV)	*Bemisia tabaci*
Pepper golden mosaic	Pepper golden mosaic virus (PepGMV)	*Bemisia tabaci*
Potato yellow mosaic	Potato yellow mosaic virus (PYMV)	*Bemisia tabaci*
Soybean yellow mosaic	Soybean mosaic virus (SMV) and Mungbean yellow mosaic india virus (MYMIV)	*Bemisia tabaci*
Sweet potato chlorotic stunt	Sweet potato chlorotic stunt virus (SPCSV)	*Trialeuroides vaporariorum* and *Bemisia tabaci*
Sweet potato mild mottle	Sweet potato mild mottle virus (SBMMoV)	*Bemisia tabaci*
Sweet potato yellow dwarf	Sweet potato yellow dwarf virus (SPYDV)	*Bemisia tabaci*
Tomato chlorosis	Tomato chlorosis virus (TCV)	*Trialeuroides vaporariorum*
Tomato yellow mosaic	Tomato yellow mosaic virus (ToYMV)	*Bemisia tabaci*
Vein yellowing of cucumber	Cucumber vein yellow virus (CVYV)	*Bemisia tabaci*
Yellow leaf curl of tomato	Tomato yellow leaf curl virus (TYLCV)	*Bemisia tabaci*
Yellow vein mosaic of Urd	Urd yellow vein mosaic virus	*Bemisia tabaci*

	(BGYMV)	
Yellow vein mosaic of Bitter gourd	Bittergourd yellow mosaic virus (BGYMV)	*Bemisia tabaci*
Yellow vein mosaic of pigeon pea	Pigeon pea yellow vein mosaic virus (PYMV)	*Bemisia tabaci*
Yellow vein mosaic of Mung	Mungbean yellow mosaic virus (MYMV)	*Bemisia tabaci*
Yellow vein mosaic of okra	Okra Yellow vein mosaic virus (OYVMV)	*Bemisia tabaci*
Yellow vein mosaic of pumpkin	Pumpkin yellow vein mosaic virus (PYVMV)	*Bemisia tabaci*
Yellow vein of potato	Potato yellow vein virus (PYVV)	*Trialeuroides vaporariorum*

Note: Vector for transmitting leaf curl disease in vegetables- whitefly

Chapter -7
Transmission of plant viruses by Thrips

Taxonomic classification:

Kingdom: Animalia.
Phylum: Arthropoda.
Class: Insecta.
Order: Thysanoptera
Family: Thripidae
Genus: *Thrips*
Species: *tabaci*

Morphological identification:

Thrips are very small insects (an average length is 1-2 mm), widespread throughout the world. They are divided into two suborders, the Terebrantia, with a blunt or angled body end, and the Tubu- lifera, in which the abdomen forms a tube at the end **(Moritz 1994; Moritz *et al.* 2000).** The thrips mouthparts are composed of two maxillary stylets and one mandibular stylet (Right mandible is absent) that form a feeding apparatus **(Cranston and Gullan, 2003)** and which also forms asymmetrical mouthparts. Some of the vector species reproduce mainly parthenogenetically.

Nature of damage

Thrips are polyphagous insects that have many hosts. The larvae are rather inactive but the adults have wings and are very active. Adult thrips feed by sucking the contents of sub epidermal cells. They rasp the cells off the upper surface of young leaves, while they are still in the bud. Silvery scars appear on the upper surface of leaves and those leaves distorted. Adults primarily feed on the floral parts such as petals and pollen, which results in spotting, deformation of flower buds, and reduced fruit set **(Childers and Bullock, 1999).**

Virus species transmitted by thrips:

A small number of thrips species are also the sole vectors or carriers of all viruses. About 10 species of thrips of the family Thripidae (Thysanoptera) are the vectors of about a dozen viruses belonging to *Carmovirus* (Tombusviridae*)*, *Ilarvirus* (Bromoviridae), *Sobemovirus* (Solemoviridae*)*, *Machlomovirus* (Tombusviridae) and *Tospovirus* (Bunyaviridae) **(Jones, 2005)**.

Thrips-transmitted *tospoviruses* (genus Tospovirus, family Bunyaviridae) are a major group of plant viruses affecting at least 1,090 host-plant species in 15 monocotyledonous and 69 dicotyledonous families' worldwide **(Parrella *et al.* 2003)**

Plant virus groups transmitted by important species of thrips and their mode of transmission

Genus (Family)	Mode of transmission	Thrips species
Tospovirus (Bunyaviridae)	Persistent, circulative, propagative	*Frankliniella occidentalis* *Thrips tabaci* *Frankliniella schultzei* *Scirtothrips dorsalisa* *Frankliniella fusca* *Ceratothripoides claratris* *Thrips palmi* *Frankliniella intonsa* *Frankliniella gemina* *Frankliniella cephalica*
Ilarvirus (Bromoviridae)	Non persistent, Semi persistent	*Scirtothrips dorsalis* *Thrips tabaci* *Frankliniella schultzei* *Franklinothrips orizabensis* *Franklinothrips vespiformis*

Important species:

Different species of thrips belonging to genera *Frankliniella, Scirtothrips, Microcephalothrips*, and Ceratothripoides transmit plant viruses.

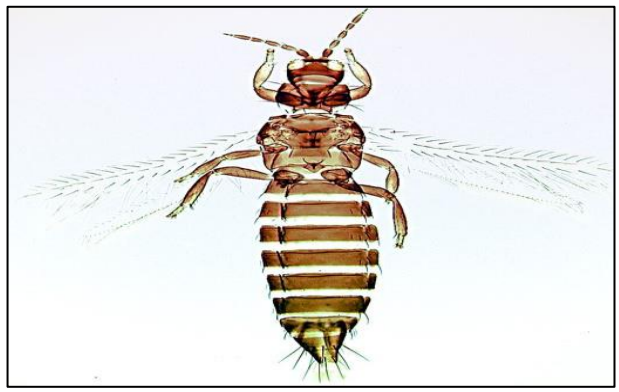
1. *Frankliniella occidentalis*



The life cycle parameters of thrips are extremely variable from one species to another. *F. occidentalis* adults insert bean-shaped eggs into leaf, flower, or fruit tissues **(Hansen *et al.* 2003).** First instars hatch within 5 days and moult into second instars within a day at 30°C. Second instars develop into prepupae within 4 to 5 days **(Lowry *et al.* 1992).** Late second instars usually fall into the soil and pupate, but some can remain on the plant **(Broadbent *et al.* 2003).** The no feeding pupal stage is mostly immobile and has distinct and well-developed wing pads (**Lewis, 1973).** Adults emerge within 3 days at 30°C (**Lowry *et al.* 1992).** Thrips development is known to be dependent on temperature. Adults live up to 3 weeks and there may be as many as **20 generations** per year.

2. *Frankliniella schultzei*

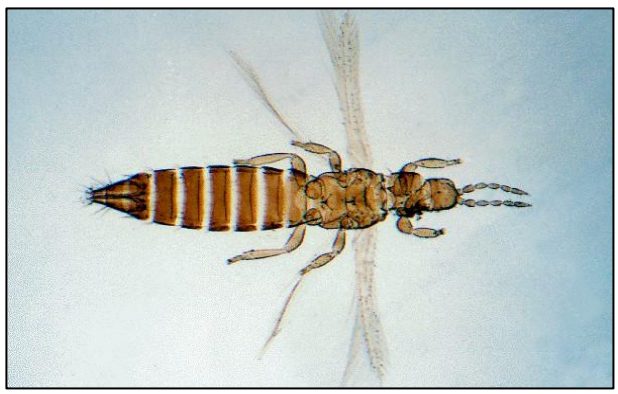
Frankliniella schultzei is an important vector of tomato spotted wilt virus, and breeds on the flowers and leaves of many plants. Both sexes fully winged; existing as two discrete color morphs, either body colour brown, with pronotum, tibiae and tarsi paler, antennae brown with segments III-V yellow at base, or body colour yellow with faint shadings on tergites, and antennal segments VI-VIII brown; fore wings pale with dark setae.



Life cycle usually takes about 2-5 weeks (**Hill, 1983**); with eggs hatch in 5-8 days, nymphs undergo 3 instars in 8-10 days, pupation lasts 4-7 days (**Gahukar, 2004**). They rasp the cells off the upper surface of young leaves, while they are still in the bud (**Hill, 1983**). Silvery scars appear on the upper surface of leaves and those leaves distorted. Adults prefer young leaves and flowers, nymphs leaf buds (**Gahukar, 2004**).

3. *Thrips tabaci*

Thrips tabaci is a highly polyphagous and economically harmful pest of cultivated plants, particularly a pest of onion, leek and cabbage, and important as a tospovirus vector. Both sexes fully winged. Body color varying from yellow to dark brown, apparently depending on the temperature during development; The full cycle can take about 15 days (**Lewis, 1973**) to over a month (**Ananthakrishnan, 1971**). Adults may live for more than one month producing several generations in one year depending on seasons. Plants infested with this species develop a spotted appearance on the leaves, subsequently turning into pale white blotches due to drainage of sap. The bulbs become unhealthy, becoming reduced in size in partially infested plants; in acute infestations the leaf tips fade, the lower parts become blighted and the plants ultimately fade up and die (**Ananthakrishnan, 1971**).



Mode of Transmission

Thrips are known to transmit tospoviruses in a persistent propagative manner (**Ullman *et al*. 1997).** Both larval and adult stages of thrips vectors can actively feed on virus infected host plants, when there is a temporary association between midgut, visceral muscles and salivary glands **(Moritz *et al*., 2004)** but only early larval instars can acquire the virus and later instar larvae and adults can transmit the virus after a latent period (**Ullman *et al*. 1997**, **Whitfield *et al.* 2005**, **Persley *et al.* 2006).** They are reintroduced into a plant with the saliva of a feeding adult **(Palmer *et al.,* 1990).** However, nonviruliferous adult thrips seem not to acquire the virus when feeding on infected plants (**Assis Filho *et al*., 2004).** An adult may remain viruliferous for life, which may be 20-40 days.

By far the most important thrips transmitted viruses are the ***tospoviruses,*** which include the widespread and severe **tomato spotted wilt virus** and the impatience necrotic spot virus. In tospo viruses, **only the larvae acquire the virus but not the adults, and their ability to acquire it decreases with age**. Larvae sometimes acquire the virus after feeding on a diseased plant for as little as 5 minutes, but usually they must feed for more than an hour both in acquiring and in inoculating the virus. Between acquisition and inoculation, there is a latent period of 3-4 days before the virus can be transmitted, during which time virus multiplies **(Sakimura, 1963).**

The virus is passed from the larvae to the adults which can transmit it, although erratically, for as long as they live. In addition, tospoviruses are not transmitted **transovarially** (**Wijkamp *et al.* 1996).** Thus, each new generation of thrips vectors must acquire the virus as larvae. There are distinct associations between thrips species and their ability to transmit specific tospoviruses **(Jones, 2005).**

List of diseases transmitted through Thrips

Disease	Causal organism	Vector
Blackberry chlorotic ringspot	Blackberry chlorotic ringspot virus (BCRV)	Thrips
Capsicum chlorosis	Capsicum chlorosis virus (CaCV)	Melon thrips *Thrips palmi*
Ground nut ring spot	Groundnut ring spot virus (GRSV)	Western flower thrips *F. occidentalis* (Common blossom thrips/cotton thrips) *F. schultzei*
Iris yellow spot virus disease of onion and garlic	Iris yellow spot virus (IYSV)	Onion thrips *Thrips tabaci*
Onion purple blotch	Fungi *Alternaria porri*	*Thrips tabaci*
Peanut bud necrosis	Ground bud necrosis virus (GBNV)	*Frankliniella schultzei,* *Thrips palmi*
Peanut stem necrosis	Tobacco streak virus (TSV)	Common blossom thrips/ cotton thrips *Frankliniella schultzei*
Peanut yellow spot	Peanut yellow spot virus (PYSV)	*Scirtothrips dorsalis*
Tobacco ring spot	Tobaaco ring spot virus (TRSV)	*Thrips,* *Xiphinema americanum* (Nematode), Aphids and Mites also
Tobacco streak disease	Tobacco streak virus (TSV)	*Scirtothrips dorsalis* *Thrips tabaci* *Frankliniella schultzei* *Franklinothrips orizabensis* *Franklinothrips vespiformis*

Tomato spotted wilt	Tomato spotted wilt virus (TSWV)	Western flower thrips *Frankliniella occidentalis*
Watermelon bud necrosis virus	Watermelon bud necrosis virus (WBNV)	Melon thrips *Thrips palmi*
Yellow spot of pine apple	Tomato spotted wilt virus (TSWV)	*Thrips tabaci*

Note: Tomato spotted wilt virus is specially acquired by nymphs but only adult thrips transmits it Tobacco ring spot virus transmitted only by nymphs and not by adult thrips. This virus is also transmitted by Nematodes. (*Xiphinema americanum*, Mites and Aphids).

Chapter -8
Transmission of plant viruses by Mealy bugs and other bugs

Taxonomic classification:

Kingdom: Animalia.
Phylum: Arthropoda.
Class: Insecta.
Order: Hemiptera
Family: Pseudococcidae
Genus: *Planococcus*
Species: *citri*

Mealy bugs (Pseudococcidae) are destructive insect pests of crop plants. Mealy bugs are either monophagous **(Franco *et al.,* 2009)** or polyphagous. Mealybugs perfectly homogenize with their host plant, thanks to the wax produced by the host plant, which covers them and offers them camouflage. It is estimated that 149 mealybug species feed on plants with their piercing and sucking feeding behaviour. The *Planococcus* species are the most common and destructive **(Cox, 1989)** and causing severe mechanical damages to crop plants.

Morphological identification:

Mealy bugs are white, soft-bodied, cottony-looking insects equipped with piercing/sucking mouth parts under the order hemiptera. They are like plant scale insects and aphids in sucking the fluids from leaves and stems from the plants for the requirement of essential nutrients.

Mealy bugs are important as virus vectors primarily on some perennial plants in the tropics and subtropics. They move from plant to plant, mostly as crawling nymphs, through leaves of adjacent plants being in contact with each other; by ants tending the mealy bugs and moving them from one plant to the other; and occasionally by wind.

Virus species transmitted by Mealy bugs:

Due to their less mobile nature, they are less effective in transmitting plant viruses than aphids, leafhoppers and other insect vectors. In addition, the sex and age of mealybugs affect virus transmission rates. For example, old female mealybugs are less efficient in transmitting plant viruses **(Selvarajan *et al*., 2016)**. Also, the life stages of the nymph affect their transmission rate of viruses (adults are more effective than nymphs) **(Sastry, 2013).**

Mealy bugs feed on the phloem and they are vectors of the ***badnaviruses*** of Caulimoviridae family such as the cacao swollen shoot virus (CSSV), several ***closteroviruses*** of Closteroviridae (Closteroviridae generally consists of four genera- *Closterovirus, Ampelovirus* and *Crinivirus, Velarivirus*) **(Fuchs *et al.,* 2020)** family such as grapevine leaf roll associated viruses and the pineapple mealy bug wilt associated virus, and the **trichoviruses,** such as grape viruses A and B.

Mealy bugs are the main vectors of Ampeloviruses. In a **semi-persistent manner**, mealybugs transmit Ampelovirus and other viruses in the Ampelovirus genus in a semi-persistent mode (GLRaV 3).Ampeloviruses have a non-enveloped capsid, 1400–2200 nm long virion, 13.0–18.5 kb segmented genome and filamentous shape. The genome of Ampelo-like air potato virus 1 (AiPoV1) is estimated to be around 13,398 nucleotides. Most Ampeloviruses are transmitted by *Dysmicoccus brevipes* (*Pseudococcus brevipes*), *Dysmicoccus neobrevipes* and *Pseudococcus longispinus* **(Dey *et al.,* 2018)**.

The genus *Closterovirus* belongs to the family Closteroviridae. Closteroviruses have two huge gene modules: one for genome replication, and the other for genome packaging and transport within the cells. The genome of Closterovirus is linear, positive RNA, with a maximum size of 19.3 kb **(Dolja and Koonin, 2013)**

The genus *Badnavirus* belongs to the Caulimoviridae family. Viruses found in Caulimoviridae have semicircular double-stranded DNA. They have a genome length range of 7.2–9.2 kbp. Eight divisions (*Badnavirus, Caulimovirus, Cavemovirus, Petuvirus, Rosadnavirus, Solendovirus, Soymovirus* and *Tungrovirus*) are members of the Caulimoviridae family based on host range, insect vector and the basis of genome organization **(Ferreira *et al*., 2019).** Badnaviruses affect monocots and dicots. Most Badnaviruses are horizontally transmitted through mealybugs and aphids.

Plant virus groups transmitted by mealy bugs

Genus (Family)	Mode of transmission	Mealybug species
Ampelovirus (closteroviridae)	semi-persistent manner	*Dysmicoccus brevipes* (*Pseudococcus brevipes*), *Dysmicoccus neobrevipes* and *Pseudococcus longispinus Maconellicoccus hirsutus*
Badnavirus (Caulimoviridae)	Semi persistent manner	*Planococcus citri Saccharicoccus sacchari*
Closterovirus (closteroviridae)	Semi persistent manner	*Dysmicoccus brevipes Dysmicoccus neobrevipes*
Vitivirus (Betaflexiviridae)	Semi persistent manner	*Pseudococcus, Planococcus, Phenacoccus, Heliococcus, Neopulvinaria, Parthenolecanium, Cavariella and Ovatus*

Important species:

1. Citrus mealy bug *(Planococcus citri):*



Adult females of *Planococcus citri* are 2.5 - 4 mm long and 2-3 mm in breadth. Seen dorsally, they have an oval form; they are soft and covered with a fine waxy material. They move very little. They can be distinguished from other mealy bugs by their possession of 18 pairs of relatively short wax rods round the edge of the body, and two slightly longer 'tail filaments'. The tail filaments are always shorter than 20% of body length. They produce little wax, so that the light yellow to pink body is visible through its waxy covering. There is often a darker longitudinal stripe running over the body.

The adult males are short lived and can be hard to spot. They are smaller than the females, have two pairs of wings and two long tail filaments

Life cycle duration (egg to egg-laying adult) ranges from 20 to 44 days **(Betrem, 1936).** Citrus mealy bug populations are generally composed of equal numbers of males and females.
It has reported as a vector for many viral diseases viz, Banana streak virus disease, Citrus Yellow Mosaic and Piper yellow mottle virus disease

2. Striped mealy bug *(Ferrisia virgata):*



The striped mealy bug, *Ferrisia virgata* Cockerell, is a small insect that is a pest of a broad range of plants. Mealy bugs are sap-feeding insects that tap into the phloem via a piercing, straw-like mouthpart known as a stylet. Severe infestations of mealy bugs can be fatal to a plant. Large populations of mealy bugs appear as accumulations of white, cottony-looking wax on the plant. This wax is produced by special glands and gives the insects the “mealy” appearance from which the name “mealy bug” is derived. Eggs are deposited on the pad and the first instar nymph’s hatch within a few hours **(Awadallah *et al*. 1979).** There are three to five generations per year **(Ammar *et al*. 1979)**

The striped mealy bug is known to vector plant pathogens, a trait uncommon in mealy bugs. It has been reported to transmit *Cocoa swollen shoot virus*, *Citrus tristeza virus*, and *Piper yellow mottle virus* **(Ameyaw *et al*. 2014)**

Mechanism of transmission

The process of virus transmission by mealy bugs can be divided into the following consecutive stages or periods.

i. Period before acquisition feeding, during which the vectors may either starve or feed. The term used is preliminary fasting or preliminary feeding.
ii. The time the vectors spend on virus infected source plant is called acquisition access time (AAT).
iii. The period between the end of AAT and the next feed is termed post acquisition fasting or post acquisition feeding to indicate fasting or feeding after AAT but before the actual test feeding on healthy plants.
iv. The time the vectors stay on virus indicator or test plants is called inoculation access time (IAT).

Compared to aphids and whiteflies, mealy bugs are transmitters of a few genera of plant viruses. Due to their less mobile nature, they are less effective in transmitting plant viruses than aphids, leafhoppers and other insect vectors. In addition, the sex and age of mealy bugs affect virus transmission rates. For example, old female mealybugs are less efficient in transmitting plant viruses **(Selvarajan *et al.,* 2016)**. The life stages of the nymph affect their transmission rate of viruses (adults are more effective than nymphs).

Like *Ampelovirus, Badnaviruses* are transmitted by mealy bugs in a semi-persistent manner. In semi-persistent (foregut- borne) virus transmission, viruses are spread from the stylet of the insect up to the foregut. The virus does not spread beyond the foregut of the insect vector. Within 20 minute-periods, the mealy bug picks up the virus and infects the host **(Ameyaw *et al*., 2014).** The virus does not reproduce and multiply in the vector, and retention of the virus in the host spans from hours to days. During feeding, the saliva of some mealy bug species, especially *Maconellicoccus hirsutus*, causes harmful effects to plants.

Mealy bugs acquire and transmit viruses with or without association with other viruses. For example, mealy bugs (*Dysmicoccus brevipes* and *Dysmicoccus neobrevipes*) were found to transmit Pineapple Mealy bug-associated virus-3 (PmaV-3) without the transmission of PmaV-1 **(Sether *et al.,* 2005)**

Mealy bugs acquire the viruses after feeding on diseased plants for only a few, about 20, minutes and retain the virus for a few, up to 24 hours, so the transmission resembles the **non-persistent or semi persistent** mechanism of transmission by aphids. No phytoplasma or other plant-pathogenic bacterium has ever been found to rely on scale insects for transmission.

Other bugs that transmit plant viruses include the mirid bugs, which transmit some **sobemoviruses** in manners that have characteristics of **non-persistent, semi-persistent**, and beetle-like transmission, and the piesmatid bugs, which transmit beet leaf curl virus in a persistent **propagative manner.**

List of diseases transmitted through Mealy bugs

Disease	Causal organism	Vector
Banana streak virus disease	Banana streak virus (BSV)	Citrus mealy bug *Planococcus citri*
Citrus Yellow Mosaic	Citrus yellow mosaic virus (CYMV)	Citrus mealy bug *Planococcus citri*
Cocoa swollen shoot disease	Cocoa swollen shoot virus (CSSV)	Several species of Mealy bugs
Grape vine leaf roll	Grape vine leaf roll associated virus (GLRaV)	Grapevine mealy bug *Maconellicoccus hirsutus*
Mealy bug wilt disease/ pine apple root wilt	Pine Apple Mealybug Associated Viruses (PMWaV)	Pink Pineapple mealy bug *Dysmicoccus brevipes* *Dysmicoccus neobrevipes*
Piper yellow mottle virus disease	Piper yellow mottle virus (PYMV)	*Ferrisia virgata* (Striped mealy bug) *Planococcus citri* (Citrus mealy bug) *Pseudococcus elisae* (Banana mealy bug)
Sugarcane bacilliform virus disease	Sugarcane bacilliform virus	Pink sugarcane mealy bug *Saccharicoccus sacchari*
Sugarcane mild mosaic	Sugarcane mild mosaic virus (SCMMV)	Pink sugarcane mealy bug *Saccharicoccus sacchari*

Chapter -9
Virus transmission by insects that have biting/chewing mouth parts (beetles, weevils, Earwigs and Flies)

Beetles and weevils (Coleoptera)

Taxonomic classification:

Kingdom: Animalia.
Phylum: Arthropoda.
Class: Insecta.
Order: Coleoptera
Family: Chrysomelidae, Coccinellidae, Curculionidae and Meloidae


Chrysomelid beetle

Coleoptera is the largest insect order accounting for over 360,000 species, which constitutes 40% of the known insect species in the world. Beetles are not mentioned in the first place as disease vectors, but some of them cause considerable damages through the transmission of plant pathogens. Here, we present an overview of beetles as vectors of plant pathogens, including viruses, bacteria, nematodes, fungi, and Oomycota, which are responsible for developing plant diseases with a significant impact on crop yield, and quality (**Salaau Rojas, 2013; Pan *et al*., 2018).**

Beetle vectors of plant viruses are known in four families (Chrysomelidae, Coccinellidae, Curculionidae and Meloidae) **(Gergerich, 2001).** Among 70 vector species, 30 from the family Chrysomelidae. Most of the beetle vectors are tends to eat plant cells between the leaf veins and regurgitate during feeding, thereby bathing their mouthparts with sap and virus.

Virus species transmitted by Beetles:

All known beetle transmitted viruses are ss (+) RNA viruses with isometric virions, without an envelope.

Virus transmission by beetles, however, is specific between each virus and its vector. Beetles have biting and chewing type of mouth parts and lack of salivary glands. Beetles have a unique mode of transmission of at least six groups of plant virus genera: ***Machlomovirus*** (the name comes from **Ma**ize **ch**lorotic **mo**ttle virus, MCMV), ***Bromovirus*** (the name comes from **Bro**me **mo**saic virus, BMV), ***Carmovirus*** (the name comes from **Car**nation **mo**ttle virus, CarMV), ***Comovirus*** (the name comes from **co**wpea **mo**saic virus, CPMV), *Sobemovirus* (the name comes from **so**uthern **be**an **mo**saic virus, SBMV), *and Tymovirus* (the name comes from **T**urnip **y**ellow **mo**saic virus, TYMV)**(Scott and Fulton, 1978; Gedling *et al*., 2018).** Most of these viruses are small (25 to 30 nm in diameter), stable, reach high concentrations, and are easily transmitted by sap. These viruses can also be translocated through the xylem of the plant.

Important plant virus species transmitted by beetles species and their mode of transmission

Genus (Family)	Mode of transmission	Beetle species
Comovirus (Secoviridae)	Semi persistent	Chrysomelid beetle *Cerotoma ruficornis*
Sobemovirus (Solemoviridae)	Semi persistent	Chrysomelid beetles *Dicladispa viridicyanae* *Sesselia pusilla* *Chaetocnema pulla* *Chaetocnema dicladispa*
Carmovirus (Tombusvirudae)	--	Flea beetles *Psylloides sp* *Phyllotreta sp*
Bromovirus (Bromoviridae)	Semi persistent	Chrysomelid beetles *Oulema melanopus*
Machlomovirus (Tombusviridae)	Semi persistent	Chrysomelid beetle *Oulema melanopus*

Dermaptera (Earwigs)

Taxonomic classification:



Kingdom: Animalia
Phylum: Arthropoda
Class: Insecta
Order: Dermaptera
Family: Forficulidae
Genus: *Forficula*
Species: *auricularia*

Morphological identification:

Adult earwigs (Dermaptera: Forficulidae) have uniform brown and long slim bodies with light brown or yellow legs and pincers (also called "forceps," which are long and curved in male earwigs, while those of females are almost straight) on the back of their abdomen. European earwig, *Forficula auricularia* L., is a polyphagous insect that damages vegetables and flowers in gardens and greenhouses. These feed on the shoots of young seedlings, damaging the plant so that it will not be able to yield a crop. They also feed on soft plant shoots, such as corn silk, and eat small holes in foliage and flowers, and sometimes ripened fruits are infested. **Markham and Smith, 1949** reported the transmission of the *turnip yellow mosaic virus* by this earwig to crucifers under laboratory conditions.

Viruses transmitted by earwigs:

Virus transmission by insects with chewing mouthparts (e.g., grasshoppers, earwigs, beetles, and the larvae of moths/butterflies and flies) was reported in early research on contact-transmitted viruses with stable particles and high titers, such as *Tobamoviruses* and *Potexviruses*

Mode of transmission of viruses by insects having biting and chewing mouthparts

More than 70 species of beetles are known to transmit viruses that infect economically important vegetables and grain crops. It is estimated that beetles transmit approximately 11% of insect-borne viruses **(Smith *et al.,* 2017)**.

When a beetle is an efficient vector and can acquire and can transmit the virus after feeding for a few seconds and retain virus up to 20 days. Beetles with chewing mouthparts disrupt tissue continuity during feeding and wounding caused by them can constitute a point of entry to plant pathogens.

Beetle-borne viruses have a unique mode of transmission. The viruses are transmitted in the beetle's regurgitant and there is no latent period in the vector. The original assumption was that regurgitant components selectively inactivate particles of beetle non-transmissible viruses. Some beetle-borne viruses are CV, as they were found to move into the insect haemolymph immediately after ingestion. Beetles can also be rendered viruliferous by injecting virus into the haemolymph. The virus does not propagate in the beetle as the virus titre declines with time.

Viruses not transmissible by beetles were mechanically infectious to wounded hosts, but when regurgitant was added to the inoculum mixture, only beetle-borne viruses remained infectious. **(Fereres, 2015)**

Most of the beetle vectors eat plant cells between the leaf veins and regurgitate during feeding, bathing their mouthparts with sap and virus particles, therefore beetle-associated viruses can be deposited into a chewing wound. Virus particles are translocated in the xylem elements to parts of the plants away from the site where they were deposited by an insect **(Gergerich and Scott, 1988, 1991; Gedling *et al.,* 2018).**

Noncirculative viruses can be transmitted in a semipersistent manner by many groups of insects including beetles **(Raccah and Fereres, 2009).** These viruses are retained in the foregut, a chitinous anterior region of the insect alimentary canal (**Mauck *et al.,* 2018).** Some viruses move into the beetle haemolymph immediately after ingestion (**Fereres and Raccah, 2015)**

It was indicated that a beetle could get viruses after a single bite of plant tissue, but the efficiency of acquisition increases with more extensive feeding **(Fulton and Scott, 1977).** Beetles can acquire and transmit the virus after feeding for a few seconds and can retain the virus from 1 to 10days **(Agrios, 2008)** depending on the beetle species.

Bacterial transmission:

Bacterial pathogens use **circulative, propagative** transmission. Plant bacterial disease can be manifested by several types of symptoms, including blights, galls, and soft rots. Bacteria can be present on the plant surface in droplets and sticky exudates released through cracks, wounds in the infected area, or through natural openings (including stomata, nectar Rhodes, and hydathodes). Insects can be attracted by sweet bacterial exudates. During insect feeding, bacteria stick to mouthparts and other parts of the insect body **(Agrios, 2008).** Some bacteria obtained with plant material migrate to the insect gut epithelium and are deposited on wounds through infected faecal droppings **(Mitchell and Hanks, 2009).** For the development of a new bacterial infection, a fresh wound or the natural opening and enough moisture in the plant surface are needed. Thanks to this, bacteria multiply and move into the plant, and bacterial infection is developing **(Agrios, 2008).**

Fungi are **non-circulative** but may be propagative or nonpropagative, depending on the transmitted life stage (spores, in a yeast-like state, or as mycelia), and persistent, semipersistent, or nonpersistent.

List of diseases transmitted through Beetles, Weevils, earwigs and Flies

Disease	Causal organism	Vector
Bacterial soft rot of potato	Bacteria *Erwinia carotovora*	*Delia platura* (Seed corn maggot)
Bacterial wilt of corn	Bacteria *Erwinia carotovora*	seed corn maggots
Bacterial wilt of cucurbits	Bacteria *Erwinia tracheiphila*	*Diabrotica undecimpunctata,* *Acalymma vittatum* (Striped and spotted cucumber

		beetle)
Bean pod mottle	Bean pod mottle virus (BPMV)	Chrysomelid beetles *Cerotoma trifurcate* *Colaspis brunnea* *Colaspis lata* *Diabrotica blateata* *Diabrotica undecimpunctata* *Epilachna varivestis* (coccinellidae) *Epicauta vittata* (Meloidae)
Bean rugose mosaic	Bean Rugose mosaic virus (BRMV)	Chrysomelid beetles *Cerotoma ruficornis*
Blackgram mottle	Blackgram mottle virus (BMoV)	Mexican bean beetle *Epilachna varivestis* *Cerotoma trifurcata*
Brome mosaic	Brome mosaic virus (BMV)	Chrysomelid beetles *Oulema melanopus*
Cocks foot mottle	Cocks foot mottle virus (CfMV)	Chrysomelid beetles *Oulema melanopus* and *Oulema gallaeciana*
Dutch elm disease	Fungi *Ophiostoma ulmi*	Elm bark beetles *Scolytus multistriatus* *Scolytus scolytus* *Scolytus pygmaeus* *Scolytus triarmatus*
Maize chlorotic mottle	*Maize chlorotic mottle virus* (MCMV)	Chrysomelid beetle *Oulema melanopus* *Systena frontalis* *Chaetocnema pulicaria* *Diabrotica undecimpunctata* *Diabrotica longicornis* *Diabrotica virgifera virgifera*
Oak wilt disease	Fungi *Ceratocystis fagacearum*	Sap beetles (Family: Nitidulidae)
Olive knot	Bacteria *Pseudomonas savastanoi*	*Bactrocera oleae* (Olive fruitfly) (Diptera: Tephritidae)
Pine wilt disease	*Bursaphelenchus xylophilus* (Pinewood nematode)	*Monochamus caroliensis* *Monochamus alternatus* (Cerambycid beetles)
Potato black leg	Bacteria *Erwinia carotowora*	*Hylemyia cilicrura* (seed corn maggot)
Potato scab	Bacteria *Streptomyces scabies*	*Epitrix cucumeris* (Potato flea beetle)
Red ring of coconut	*Bursaphelenchus cocophilus* (Nematode)	*Rynchophorus palmarum* (American palm weevil)

Rice yellow mottle	Rice yellow mottle virus (RYMV)	Chrysomelid beetles *Dicladispa viridicyanae* *Sesselia pusilla* *Chaetocnema pulla* *Chaetocnema dicladispa*
Stewart disease in corn	Bacteria *Pantoea stewartia*	Corn flea beetles *Chaetocnema pulicaria* *Chaetocnema denticulate* *Diabrotica undecimpunctata* *Diabrotica longicornis* *Agriotes mancus*
Turnip crinkle	Turnip crinkle virus (TCV)	Flea beetles *Psylloides sp* *Phyllotreta sp*
Turnip yellow mosaic	Turnip yellow mosaic virus (TYMV)	Flea beetles, Grasshoppers and Earwig

Note: Bacterial diseases are transmitted by beetles

Chapter -10

Transmission of plant viruses by Leafhoppers and Plant hoppers

Taxonomic classification

Kingdom: Animalia.
Phylum: Arthropoda.
Class: Insecta.
Order: Hemiptera
Family: Cicadellidae

Morphological identification

Leafhopper adults are small to medium-sized, ranging from 2 to 30 mm in length but rarely exceeding 12 mm. They usually have somewhat cylindrical or wedge-shaped bodies **(Dietrich, 2005; Munyaneza *et al*., 2012).** Leafhoppers are very active insects and use both wings and legs for locomotion. Leafhopper adults can jump and/or fly, while immature leafhoppers, since they do not have developed wings, mostly jump or run sideways **(Shah and Zhang, 2018).**

They are hemimetabolous, thus nymphs and adults feed similarly and are in the same physical location-often both immature and adults can transmit phytoplasmas. Their feeding is non-destructive, promoting successful inoculation of the plant vascular system without damaging the conductive tissues and eliciting defensive responses. Leafhoppers lay eggs that hatch to nymphs which pass through several moults before becoming adults. Some of them overwinter as eggs, some as adults, and some as immature forms.

Nature of damage

They all feed by sucking sap from phloem elements of plants. Their feeding behaviour is similar to that of aphids in that the mouthparts, surrounded by the salivary sheath, penetrate the phloem of host plants. Leafhopper damage is characterized by light-colored speckling on plant leaves caused by sucking of sap and plant juices from within the plant tissue. Only a few species of hoppers transmit pathogens, such as those that cause curly top virus and aster yellows **(Burrows and Sutton, 2013)**

Virus species transmitted by leafhoppers

Leafhoppers (family Cicadellidae) transmit over 80 known types of plant disease, including ones caused by viruses, mycoplasma-like organisms, and spiroplasmas (**Sarwar, 2020)**. Most leafhopper vectors transmit viruses in a circulative manner and many of these viruses are propagative in their vector **(Klein, 2001).** Leaf hoppers are known to vectors *Geminivirus, Marafivirus, Rhabdovirus, Tenuivirus, Phytoreovirus, Fijivirus* **(Nault and Ammar, 1989)**

Plant virus groups transmitted by leafhoppers and plant hoppers and their mode of transmission

Genus (Family)	Mode of transmission	Genera
Geminivirus (Geminiviridae)	Circulative	*Cicadulina* *Orosius* *Circulifer* *Nesoclutha* *Micrutalis*
Marafivirus (Tymoviridae)	Propagative	*Dalbulus* *Macrosteles*
Rhabdovirus (Rhabdoviridae)	Propagative	*Cicadulina* *Graminella* *Laodelphax* *Nephotettix* *Perigrinus* *Sogatella*
Tenuivirus (Phenuiviridae)	Propagative	*Javesella* *Laodelphax* *Nilaparvata* *Perigrinus* *Sogatodes*
Phytoreovirus (Reoviridae)	Propagative	*Agallia* *Agalliopsis* *Nephotettix* *Recilia*
Fijivirus (Reoviridae)	Propagative	*Dicranotropis* *Javesella* *Laodelphax* *Nilaparvata* *Perigrinus* *Sogatella*

(Nault and Ammar, 1989)

Plant hoppers:

As vectors, plant hoppers (Delphacidae) have received far less attention from researchers than have aphids and leafhoppers. However, 21 vector species (13 genera) have been recorded; and, as a group, these vectors are responsible for transmitting at least 1 MLO (rice grassy stunt) and 17 viruses or suspected viruses

The two genera that have propagative viruses are *Tenuivirus*, members of which are transmitted by delphacid plant hoppers,

Mechanism of transmission:

Phytoplasmas are important phloem limited, insect transmitted pathogenic agents causing a thousand diseases, many of which are lethal, in hundreds of plant species **(Weintraub, 2007).** Only phloem feeding insects can potentially acquire and transmit the pathogen.

Virus-vector relationships:

All hopper-transmitted viruses are persistent circulative or persistent propagative, and are transmitted by only one or by a few closely related species of the hopper vectors. Only two of the 60 sub-families of leafhoppers (Cicadellidae) contain species that are vectors of viruses: the Agalliinae feed on herbaceous dicotyledonous hosts and the Deltocephalinae that feed on monocots. Of the 20 plant hopper families (Fulgoroidea), only one, the Delphacidae, have species that are vectors of viruses all of which infect monocotyledonous plants and many of them cause severe diseases on cereal crops such as rice, wheat, and corn.

Circulative viruses –

Most leafhopper and planthopper vectors transmit plant viruses in a circulative manner. The majority of leafhoppers and planthoppers transmit plant viruses multiply with the vector body. Circulative viruses can be recovered experimentally from the vector's hemolymph, can be transmitted after injection into the vector's hemocoel, are not lost after ecdysis, and may be transmitted for weeks, sometimes for the life of the vector **(Sylvester, 1980).** Only two genera of Gemini viruses (*Mastrevirus* and *Curtovirus*) are transmitted by leafhoppers in the persistent circular manner. The viruses are acquired by the vector after feeding for a few seconds to an hour. There is a latent period of about hours to days and is temperature dependent, presumably for the virus to reach the salivary glands. No circulative virus is transovarially transmitted from infective females to their progeny.

Semi-persistent transmission -

Two viruses, maize chlorotic dwarf virus (MCDV) and rice tungro spherical virus (RTSV), are **acquired** by their vectors (*Graminella nigrifrons* and *Nephotettix virescens*, respectively) from their hosts within about 15 to 30 minutes and are retained by their vectors for one to a few days. The **latent period** of these viruses may be relatively short (hours) or long (at least a week). MCDV particles have been seen in the foregut and a few other tissues but not

beyond. Hoppers egest material from the foregut once in a while during feeding and it is thought that transmission occurs during this ingestion-egestion process.

Persistent transmission –

This involves the internal movement of the virus obtained from the plant to the salivary glands of the insect vector. Some of these viruses are circulative while others are propagative. A few viruses, such as wound tumour virus and potato yellow dwarf virus, are transmitted in a transovarial passage manner **(Sinha and Shelley, 1965; Black, 1953).**

Propagative viruses–

Propagative viruses are similar to circulative viruses in several transmission properties, but they multiply in their vectors. Such multiplication can be demonstrated by transmission studies in which viruses are passed serially from insect to insect (either by needle injection or transovarial transmission) until the dilution attained in the final inoculative insects exceeds the dilution endpoint of the initial inoculum **(Whitecomb, 1972).**

Propagative viruses usually require longer mean latent periods (one or more weeks) than circulative viruses **(Sylvester, 1980).** During this period the virus replicates and invades most tissues of the insect vector. When the virus reaches the salivary glands of the vector, the latter can transmit the virus to new plants and can continue to transmit it for the rest of their life. Only a small percentage of the hoppers feeding on infected plants become vectors and of these only about 1% pass the virus through their eggs to the next generation. Various capsid proteins seem to be necessary for passage of viruses through the organs of the vector and are required for transmission.

Most of the leafhopper and plant hopper species transmit plant viruses in a circulative/propagative manner in which vectors remain viruliferous for most of their lives after a single acquisition feeding on a virus source **(Harris, 1979)**

List of diseases transmitted through Leaf hoppers and plant hoppers

Disease	causal organism	Vector
Bunchy top of papaya	Rickettsia like phloem limited bacteria	Papaya leaf hopper *Empoasca papayae*
Maize chlorotic dwarf	Maize chlorotic dwarf virus	The black faced leaf hopper *Graminella nigrifrons*
Maize mosaic	Maize mosaic virus	Corn plant hopper *Perigrinus maidis*
Maize rough dwarf	Maize rough dwarf virus	Small brown plant hopper *Laodelphax striatellus*
Maize streak	Maize streak virus	Leaf hopper *Cicadulina mbila* *Cicadulina storeyi*
Maize stripe	Maize stripe virus	Plant hopper *Perigrinus maidis*

Pierce's disease in grapevine	*Xylella fastidiosa* (Xylem inhibiting bacteria)	*Leaf hopper* (Glassy-winged sharpshooter) (*Homalodisca coagulate*) Blue green (*Graphocephala atropunctata*) Green (*Draeculacephala minarva*) Red headed (*Carneocephala fulgida*)
Potato yellow dwarf	Potato yellow dwarf virus	Leaf hopper *Agallia sanguinolenta*
Ragi mosaic	Ragi mosaic virus	Maize orange leaf hopper *Cicadulina bipunctella*
Ragi streak	Ragi streak virus-A strain	Leaf hopper *Cicadulina chinai*
Rice dwarf	Rice dwarf virus	Green leaf hopper *Nephotettix virescens*
Rice grassy stunt	Rice grassy stunt virus	Brown plant hopper *Nilaparvata lugens*
Rice hoja blanca	Rice hoja blanca virus	*Plant hopper* *Sogatodes oryzicola*
Rice orange leaf	Rice orange leaf phytoplasma	Zig-zag leaf hopper *Recilia dorsalis*
Rice ragged stunt	Rice ragged stunt virus	Brown plant hopper *Nilaparvata lugens*
Rice stripe	Rice stripe necrosis virus	Small brown plant hopper *Laodelphax striatellus*
Rice tungro disease	Rice tungro spherical and bacilliform virus	Green leaf hopper *Nephotettix virescens*
Rice yellow mottle	Rice yellow mottle virus	Chrysomelid beetles *Dicladispa viridicyanae* *Sessilia pusilla* *Chaetocnema pulla* *Chaetocnema dicladispa*

Phytoplasma

Phytoplasmas, a group of plant pathogens, belongs to the phylum **Mycoplasmatota**; class **Mollicutes**, only found in the internal organs of phloem-feeding hemipteran insects and the phloem sieve components of vascular plants.

They were originally named mycoplasma-like organisms or MLOs after their discovery in 1967. They are characterised as bound by a triple-layered membrane rather **cell wall (lack of cellwall)**, a pleiomorphic or filamentous shape, normally with a diameter less than 1 micrometer, and their very small genomes. They cannot be cultured in vitro in cell-free media.

The feeding duration necessary to acquire a sufficient titer of phytoplasma (acquisition access period), may range from a few minutes to several hours, the longer the period, the greater the chance of acquisition.

Insect vectors primarily leafhoppers, plant hoppers and psyllids have been identified for relatively few phytoplasma diseases **(Weintraub and Beanland, 2006).** They have a prokaryotic and persistent relationship with phytoplasmas. They have obligate symbiotic prokaryotes that are passed to be offspring by transovarial transmission, the same mechanism that allow the **transovarial** transmission of phytoplasmas.

Host range: Vectors with narrow host ranges, such as monophagous and oligophagous species, are generally more efficient at spreading phytoplasmas than polyphagous species that feed on a wider variety of plants. Additionally, factors like plant architecture, habitat structure, and ecotones (the transitional areas between different ecosystems) impact the movement and survival of these vectors **(Harris *et al*. 2013).**

The spread of phytoplasma-associated diseases is heavily influenced by various **ecological factors**, including the vectors' ability to acquire, inoculate, and disperse the pathogen **(Hogenhout *et al.,* 2008; Gurr *et al.,* 2015).** The efficiency of phytoplasma transmission can depend on factors like the phytoplasma load in the source plants and the life stage of the vector (nymphs versus adults). In some cases, transovarial transmission—where the pathogen is passed from parent to offspring may occur, affecting the timing and seasonality of inoculation **(Alma *et al.,* 2019)**

The phytolasmas are non-culturable parasitic prokaryotes; the mechanism of dissemination is mainly by insect vectors. The common vectors or at least those best known are members of the order Hemiptera, from the families Cicadellidae, Cixiidae, Psyllidae, Cercopidae, Delphacidae, Derbidae, Menoplidae and Flatidae. In the majority of cases transmission is only transovarial and has only been demonstrated in a few species **(Beanland *et al.,* 2000 and Hanboonsong *et al.,* 2002)**

The phytoplasma cell membranes studied to date usually contain a single immunodominant protein of unknown function that constitutes most of the protein in the membrane **(Berg *et al*.,1999)** A typical phytoplasma is pleiomorphic or filamentous in shape and is less than 1 μm in diameter. Like other prokaryotes phytoplasmic DNA is distributed throughout the cytoplasm instead of being concentrated in a nucleus.

Phytoplasma-harboring flowering plants may become sterile. The expression of genes involved in maintaining the apical meristem or in the development of floral organs is altered in the morphologically affected floral organs of phytoplasma-infected plants **(Pracos *et al.,* 2006)**

Spiroplasma

Spiroplasmas are members of the class *Mollicute*s (cell-wall-deficient bacteria) and are characterized by their helical cell shape **(Razin *et al.*, 1973).** They were discovered as mycoplasma-like helical organisms associated with citrus stubborn and corn stunt diseases **(Granados et al., 1968; Laflèche and Bové, 1970; Davis and Worley, 1973).**

The best-known species of spiroplasma are Spiroplasma citri, the causative agent of Citrus Stuborn Disease, and Spiroplasma kunkelii, the causative agent of Corn Stunt Disease. Spiroplasma citri, the type species of the genus Spiroplasma (Spiroplasmataceae, Mollicutes), is restricted to the phloem sieve tubes and transmitted by phloem sap-feeding insects, as is characteristic of the phytopathogenic mollicutes.

List of Phytoplasma and Spiroplasma diseases transmitted by leaf hoppers and other sucking pests

Disease	Causal organism	Vector
Acalypha witche's broom	*Phytoplasma*	Leafhopper
Areca nut yellow leaf/ chandiroga in kannada	*Arecanut yellow leaf phytoplasma* (AYLP)	The palm derbid *Proutista moesta*
Aster yellows	*Phytoplasma asteris*	Sharp nosed leaf hopper *Scaphytopius acutus*
Black gram phyllody	*Phytoplasma*	Common brown leaf hopper *Orosius orientalis*
Cannabis phyllody	*Phytoplasma*	American grapevine leaf hopper *Scaphoideus titanus*
Chickpea or gram phyllody	*Gram phyllody Phytoplasma*	Sesame leafhopper *Orosius albicinctus*
Citrus greening/ Huanglongbing (HLB)	*Spiroplasma citri*	Citrus psyllid *Diaphorina citri*
Citrus stubborn disease	*Spiroplasma citri*	Leafhoppers *Circulifer tenellus* *Scaphytopius nitridus* *Neoaliturus haemoceps*
Clover phyllody	*Phytoplasma trifolii*	Aster leafhopper *Macrosteles cristata*
Coconut lethal yellowing	*Phytoplasma palmae*	American palm cixiid *Myndus crudus*
Coconut root wilt	*Phytoplasma palmae*	Palm derbid *Proutista moesta*
Corn stunt	*Spiroplasma kunkelii*	Maize leafhopper

		Dalbulus maidis
Cotton stenosis	*Cotton stenosis phytoplasma*	**Whitefly** ***Bemisia tabaci***
Cotton virescence	Cotton virescence phytoplasma	Leaf hopper *Orosius cellulosus*
Cowpea witches broom	*Cowpea witches broom phytoplasma* (CWBP)	Cowpea leaf hopper *Empoasca dolichi*
Duranta little leaf	*Duranta phytoplasma*	*Scaphytopius nitridus*
Jasmine phyllody	*Phytoplasma*	*Dialeurodes kirkaldii.* Whitefly
Little leaf of brinjal	*Phytoplasma trifolii*	Brown leaf hopper *Cestius phycitis*
Maize bushy stunt	Maize bushy stunt phytoplasma	Corn leaf hopper *Dalbulus maidis* *Dalbulus eliminatus*
Mung bean phyllody	*Phytoplasma*	Common brown leaf hopper *Orosius orientalis*
Marigold phyllody	*Candidatus phytoplasma aurantifolia*	Leaf hopper *Orosius albicinctus*
Pear decline	*Phytoplasma pyri*	pear psylla *Cacopsylla pyri*
Periwinkle virescence	*Phytoplasma*	Beet leaf hopper *Neoaliturus tenellus*
Potato purple top	*Potato purple top Phytoplasma* (PPTP)	*Macrosteles spp and Hyalesthes spp.*
Rice yellow dwarf	*Phytoplasma oryzae*	Rice green leaf hopper *Nephotettix cincticeps*
Safflower phyllody	*Phytoplasma castaneae*	*Neoaliturus fenestratus*
Sandalwood spike	Sandal spike phytoplasma	**Sandalwood aphid** ***Jassus indicus***
Sesame phyllody	*Phytoplasma aurantifolia*	Sesame leafhopper *Orosius albicinctus*
Solanum little leaf	*Phytoplasma*	Leafhopper *Hishimonus phycitis*
Soyabean phyllody	*Soyabean phyllody Phytoplasma*	Common brown leaf hopper *Orosius orientalis*
Sugarcane grassy shoot	*Phytoplasma oryzae*	Aphid *Aphis sacchari*
Sugarcane streak mosaic	Sugarcane streak mosaic virus (SCSMV)	Leafhopper *Cicadulina mbila* *Cicadulina bipunctata*
Sun hemp phyllody	*Sunhemp phyllody Phytoplasma*	Common brown leaf hopper *Orosius orientalis*
Tagetus phyllody	*Phytoplasma*	Sesame leafhopper *Orosius albicinctus*

Tomato big bud	*Tomato big bud phytoplasma*	*Orosius argentatus*
Turnip phyllody	*Phytoplasma*	Sesame leafhopper *Orosius albicinctus*
Witches broom of potato	*Phytoplasma trifolii*	Leaf hopper *Hishimonus phycitis*

Note: Generally phytoplasma's are transmitted by leafhoppers but in case of grassy shoot of sugarcane, it transmits aphid *(Aphis sacchari*): cotton stenosis is transmitted by whitefly (***Bemisia tabaci):*** sandalwood spike transmitted by sandalwood aphid (*Jassus indicus*): jasmine phyllody transmitted by whitefly (*Dialeurodes kirkaldii*)

Chapter -11
Virus transmission by mites

Taxonomic classification:

Kingdom: Animalia

Phylum: Arthropoda

Class: Arachnida

Sub class: Acari

Order: Trombidiformes

Family: Eriphyidae, Tetranychidae, Tenuipalpidae

Mites are closely related to the spiders and ticks. The plant viruses are transmitted by mites belonging to different families, such as Siteroptidae, Acaridae, Tenuipalpidae, Tetranychidae, Tarsonemidae, and Eriophyidae.

Several members of Eriophyid mites (Eriophyidae) and flat mites (Tenuipalpidae) are transmitters of plant viruses **(Kitajima *et al*., 2000).** They have needle-like stylet structures that can puncture cells at the surface inducing leaf deformations.

Morphological identification

Many worm mites (Eriophyidae), false spider mites (Tenuipalpidae) and spider mites (Tetranychidae) are known as vectors of virus diseases infecting cereals, fruit trees, pulse crops and coffee plants.

Eriophyidae: Eriophyid mites are small (0.2 mm long), move little by themselves and, instead, they are spread by wind. They have two nymphal instars followed by a resting **pseudo pupa**. They complete a life cycle within two weeks. Among the Acari, only the Eriophyoidea are important vectors of plant pathogens. Currently, about a dozen plant diseases are known to be caused by the agents that are transmitted by eriophyoids and all currently recognized vector species belong to one family, the Eriophyidae. The relationship between eriophyid vector and transmitted agent is highly specific. No plant pathogen is known to be transmitted by the members of any other taxa, nor by more than one species of eriophyid. **(Oldfield and Proeseler, 1996)**

Slykhuis (1963) suggested the following three conditions that must be met to prove that an eriophyid is a vector of a plant virus:

(a) The presence of mites must be correlated with the appearance of the disease in nature.
(b) The development of disease symptoms must not depend on the continued presence of the mites. It is preferable if the causal virus can also be transmitted by artificial means without mites.
(c) The mites must not be able to induce the disease symptoms on healthy plants until after they have fed on diseased plants or have acquired virus in some other way.

Tetranychid mites are larger (0.8 mm long). Pre-adult mites readily acquire the virus and they, as well as the adults, transmit the virus efficiently.

Tenuipalpidae

The false spider mite, Tenuipalpidae, belongs to the superfamily Tetranychoidea. They are not true spider mites because they do not produce silk webbings on plants. They are also known as flat mites because most species are d orsoventrally flattened. About 30 genera and over 600 species of Tenuipalpidae have been described in the most economically important genera: *Brevipalpus* and *Tenuipalpus* (**Carrillo *et al*., 2012)**.

Virus species transmitted by mites:

Eriophyoid mites are known to vector several *Rymo-, Clostero-*, and possibly *Nepo*-viruses **(Slykhuis, 1980; Hiruki, 1992; Kim *et al*., 2001).** Eriophyid mite-transmitted, multipartite single-stranded RNA plant viruses with negative polarity recently were classified in the genus *Emaravirus*. **(Mielke-Ehret and Muhlbach, 2012).**

Plant virus groups transmitted by mites and their mode of transmission

Genus (Family)	Mode of transmission	Mite species
Closterovirus (Closteroviridae)	Persistent	*Brevipalpus californicus*
Emaravirus (Fimoviridae)	Semi persistent	*Aceria ficus* *Aceria cajani* *Phyllocoptes fructiphilus*
Nepovirus (Comoviridae)	Semi persistent	Eriophyid gall mie *Cecidophyopsis ribis*
Rhabdovirus (Rhabdoviridae)	Persistent	*Brevipalpus californicus* *Brevipalpus phoenicis*
Rymovirus (Potyviridae)	Semi persistent	*Aceria tosichella* *Abacarus hystrix*
Trichovirus (Betaflexiviridae)	Semi persistent	*Eriophyes insidiosus*

Mode of Transmission

Several members of the mite family Eriophyidae transmit viruses of the genus *Rymovirus* which cause many serious diseases in grain crops. Mites can acquire virus from infected host plants within 15 minutes from the start of feeding and can transmit it to healthy plant within a similar duration. Inoculate the virus after a minimum inoculation access period (IAP) of 60–90 min. The mite retains infectivity through the moults and remains infectious up to a period of 9 days. Mites acquire the virus as nymphs but not as adults. They carry the virus through moults and remain infective for 6 to 9 days. Mites transmitted the virus by **circulative manner but not propagative** (*All circulative viruses are propagative except Eriophyid mites carrying viruses).

List of diseases transmitted through Mites

Disease	Causal organism	Vector
Barley yellow streak mosaic virus disease	Barley yellow streak mosaic virus (BaYSMV)	Spider mite *Petrobia latens.*
Black currant reversion disease (BRD)	Black currant reversion virus (BRV)	Eriophyid gall mie *Cecidophyopsis ribis*
Cherry mottle leaf	Cherry mottle leaf virus (CMLV)	Gall mite *Eriophyes inaequalis*
Citrus leprosis	Citrus leprosis virus (CiLV)	*Brevipalpus californicus* (Acari: Tenuipalpidae)
Coffee ring spot (leaf and fruit)	Coffee ring spot virus (CoRSV)	*Brevipalpus phoenicis* (Acari: Tenuipalpidae)
Concentric ring blotch of citrus (Lepra explosive or nail-head rust)	---	Gray mite *Calacarusci trifolii*
Fig mosaic virus disease	Fig mosaic virus (FMV)	Fig mite or fig rust mite *Aceria ficus*
Grapevine panaschure	Phytoplasma Candidatus Phytoplasma solani	Grape erineum mite *Eriophyes vitis*
Hibiscus chlorotic ring spot (Hibiscus rosa sinensis)	Hibiscus chlorotic ring spot virus (HCRSV)	*Brevipalpus phoenicis* (Acari: Tenuipalpidae)
Hibiscus green spot (*Hibiscus rosa sinensis*)	Hibiscus green spot virus (HGSV)	*Brevipalpus phoenicis* (Acari: Tenuipalpidae)
Mango malformation	Fungus *Fusarium mangiferae*	Mango bud mite *Aceria mangiferae*
Passion fruit green spot disease	passion fruit green spot virus (PfGSV)	*Brevipalpus californicus* (Acari: Tenuipalpidae)
Peach mosaic virus disease	Peach mosaic virus (PcMV)	*Eriophyes insidiosus*
Pigeon pea sterility mosaic/ Red gram sterility mosaic	Pigeon pea sterility mosaic virus (PPSMV)	Pigeon pea mite *Aceria cajani*
Prunus necrosis ringspot/Peach ring spot virus	Prunus necrosis ringspot virus (PNRSV)	Plum rust mite *Aculus fockeui*

Rose rosette virus disease	Rose rosette virus (RRV)	Rose bud mite *Phyllocoptes fructiphilus*
Rye grass mosaic virus disease	Rye grass mosaic virus (RgMV)	Cereal rust mite or grain rust mite *Abacarus hystrix*
Wheat spot mosaic virus	Wheat streak mosaic virus (WSMV)	wheat blister mite *Aceria tulipae*
Wheat streak mosaic virus disease	Wheat streak mosaic virus (WSMV)	wheat curl mite *Aceria tosichella*

Chapter -12
Transmission of pathogens by Nematodes

Taxonomic classification:

Kingdom: Animalia

Phylum: Nematoda

Class: Secernentea, Adenophorea

Order: Dorylaimida, Triplonchida

Family: Longidoridae, Trichodoridae

All known virus-transmitting nematodes (eelworms) are ectoparasites. Transmission of nematodes can take several ways including direct contact between plant roots, through contaminated tools, or insect vectors. Generally, nematodes transmitted by beetles migrate to trees through wounds caused by beetle feeding and through the oviposition slits in the bark (Agrios, 2008). Healthy plants may also become contaminated by nematodes through insect faeces (Bierhals *et al.,* 2018).

Efficient transmission from infected host plants to healthy host plants by nematode vectors is an important biological feature for the development of epidemics of plant diseases incited by viruses. Both the adult and juvenile stages of the nematode vectors are capable of transmitting the associated plant viruses. Virus transmission by a vector is often characterized by some degree of specificity. (Singh *et al*., 2020)

The spread of a nematode transmitted virus from infected to healthy plants requires the following steps:

i. Virus multiplication in the host plant;
ii. Nematode feeding on the virus infected plant;
iii. Retention of the virus in the nematode's oesophagus after nematode feeding;
iv. Inoculation of a healthy plant by the viruliferous nematode and subsequent infection of the inoculated plant by the virus. **(O' Bannon and Inserra, 1990)**

Important species:

Nematodes that transmit plant viruses occur in two families: Longidoridae, which comprise the three vector genera *Longidorus, Paralongidorus,* and *Xiphinema*, and Trichodoridae, comprising two genera, *Trichodorus* and longidorid nematodes polyhedral-shaped vector *Paratrichodorus*. The isometric viruses or called nepoviruses, while the trichodorid nematodes vector straight, tubular viruses called tobraviruses **(Harrison *et al*, 1971).**

1. ***Xiphinema sp.***
   Nematodes of the genus *Xiphinema*, commonly called dagger nematodes, parasitize plants. Many of these nematodes, the majority of them belonging to the *Xiphinema americanum*-group, can transfer viruses to plants during feeding **(Taylor and Brown 1997, Gozel *et al*. 2006).** Dagger nematodes can cause economic damage and death of host crops through feeding on the roots and also by spreading viral mosaic and wilting diseases **(Van Zyl *et al*. 2012, Jones *et al*. 2013).** Viruses transmitted to food crops such as tomato, grapevine, pepper, cassava, and potato can cause more than 50% crop losses because the virus limits plant development **(Evans *et al*. 2007).**
2. ***Longidorus sp.***
   Needle nematodes (*Longidorus* spp.) are an important group of plant parasites that cause serious damage to many plant species (**Cohn, 1974).** These slender nematodes are readily recognized from most other Dorylaims by their long (2 mm to 12 mm), rather narrow body and their elongated axial spear (odontostyle) plus an extension (odontophore) about half the odontostyle length **(Hooper, 1974).** Symptoms associated with *Longidorus* generally are non-specific and may include plant stunting, root tip galls, and root forking **(Cohn, 1974).** In addition, some *Longidorus* species are vectors of nepoviruses **(Taylor and Brown, 1997).**

Characteristics of nematode- transmitted viruses

Two groups of viruses, the *tobraviruses* and the *nepoviruses*, use plant-parasitic nematodes as their transmission vector **(Taylor and Brown, 1997; MacFarlane *et al*., 2002).**

The viruses can be divided into two groups on the basis of particle shape. Those with polyhedral particles were named **Nepo** viruses, i.e. Nematode transmitted viruses with polyhedral particles. Viruses in this group are frequently referred to as ring spot viruses and are transmitted by *Xiphinema* and *Longidorus* species. The second group includes viruses with rod-shaped or tubular (TU) particles for which the name **NETU** has been coined, but in a more recently proposed classification they are called tobra viruses. The two viruses in this group, tobacco rattle and pea early browning are transmitted by *Trichodorus* species. **(Taylor, 1972)**. *Nepoviruses* and *tobraviruses* are taxonomically different from each other, but both have RNA genetic material and contain two different types of genomic RNAs.

NEPO Virus

These plant viruses belong to family Comoviridae. Plant viruses with isometric particles and transmitted by the plant parasitic nematode are called "nematode-transmitted polyhedral viruses." Nepoviruses particles measure around 30 nm in diameter and consist of bipartite single-stranded RNA (ssRNA) genomes. These viruses have a single coat protein of about 60 kD. *Nepoviruses* known to have nematodes as vectors are transmitted by species of *Longidorus*, *Xiphinema* **(Brown, 1997)** and *Paralongidorus* **(Jones *et al*., 1994).** Only about one-third of the total Nepoviruses are transmitted by nematodes. The only known nematode vectors are in the genera *Xiphinema* and *Longidorus.* In *Longidorus*, 11 species have been reported to transmit the 10 NEPO viruses, and in *Xiphinema*, 11 species have been reported to transmit 13.

Nepovirus particles are spherical in shape. *Nepovirus* species have a single coat protein (CP), which is assembled in multiple copies to form the virus particles. These have broadly similar physical and biological properties, but they share no antigenic determinants and hence are readily identifiable by serological methods.

The group includes Arabis mosaic, strawberry latent ring spot, raspberry ring spot, tomato black- ring, and tomato ring spot and tobacco ring spot viruses.

NETU Virus or Tobra viruses

Tobraviruses are rod-shaped and have straight tubular particles with two size ranges, 180-210 nm and 45-115 nm. The tobravirus groups have three members—tobacco rattle virus (TRV) (Behrens, 1899), pepper ringspot virus (Harrison and Woods, 1966), and pea early-browning virus (Bos and van der Want, 1962).

Tobraviruses are transmitted by different species of *Trichodorus* and *Paratrichodorus.* Fourteen species of *Trichodorus* have been reported to transmit various strains of two *tobraviruses*: tobacco rattle and pea early-browning. Trichodorids may retain the virus for up to a year. Acquisition time may be less than an hour to several days, depending on the feeding characteristics of the nematode.

The group includes pepper ringspot virus, tobacco rattle virus, and pea early-browning virus in different countries. Plant-parasitic nematodes acquire virus particles during feeding by sucking cell sap with a stylet. Most of the plant-parasitic nematodes transmit plant viruses by feeding ectoparasitically near the root tip on the outside of the root surface. (Singh *et al.,* 2020)

Plant virus groups transmitted by Nematodes and their mode of transmission

Genus (Family)	Mode of transmission	species
Nepovirus (comoviridae)	Semi persistent, Non persistent (or) persistent	*Xiphinema americanum* *Xiphinema diversicaudatum* *Xiphinema coxi* *Longidorus attenuatus*
NETU Virus or Tobravirus (virgaviridae)	Persistent manner	*Paratrichus pachydermatus* *Trichodorus sp*

Virus- nematode relationship

Nematodes acquire viruses when they feed on virus infected plants. During the feeding of nematodes on infected plants, they ingest virus particles. Most of the virus-vector nematodes are ectoparasitic, and they feed from the outside of the root near to the root tip. Some nematodes induce galls at the infected area of the root after completion of the feeding process. **(Singh *et al*., 2020)**

Xiphinema index can acquire grapevine fan leaf virus from infected plants in as short a time as a 5-15 minute feeding period **(Alfaro and Goheen, 1974; Das and Raski, 1968).** Up to a 24 hour feeding period may be required for other viruses.

The transmission process of the plant viruses by nematodes are completed by different phases, such as ingestion, acquisition, adsorption, retention, release, transfer, and establishment.

Ingestion: Ingestion is the process of intake of virus particles from the infected plant. This process is not essential for specific interaction between nematode and plant virus. It is required only for specific interaction between the nematode and plant. The nematode injects glandular secretions into the cell that modify the cell contents allowing them to be drawn into the nematode and ingested.

Acquisition: In this phase, Nematode vectors may acquire virus as soon as cell contents are ingested from infected roots, and transmit them during subsequent feeding on non-infected plants. There is **no latent period** within the nematode before transmission can occur. Some nematodes remain viruliferous for up to one year after acquiring the virus when the nematodes are stored a low temperatures without a host **(Bergeson *et al*, 1964)**, however, many nematode vectors in the absence of virus infected plants, either lose the virus or lose the ability to transmit within the first few months **(Mc Guire, 1973).** Nematode- transmitted viruses do not **persist** through nematode molt, nor pass through nematode eggs.

Nepo virus and tobra virus particles can be acquired by both juvenile and adult forms of vector nematode,

Adsorption: Plant parasitic nematodes feed by puncturing the plant cell wall using a spear-shaped structure, the odontostyle, which is hollow and has a narrow slit running along its length. During feeding, the odontostyle is pushed forward by protractor muscles. The nematode may repeatedly thrust the protracted odontostyle through the root surface into epidermal cells and sometimes into internally located vascular tissue cells. Nematode secretions are injected into the cell through the odontostyle, followed immediately by ingestion of the cell contents. Feeding can last from only a **few minutes to up to several hours**,

Retention: the nematodes can retain virus for long periods, for example, *P. pachydermus* nematodes were able to transmit TRV after a 2-year period of cold-storage in soil. However, virus is lost from the nematode after moulting. This occurs between each of the four stages of juvenile development and results in the replacement of the external cuticle including the lining of the oesophagus.

In some cases, there are specific associations between particular nematode species and certain viruses that lead to transmission of the viruses to healthy plants. In these associations, virus particles are physically bound (i.e., “retained”) at specific locations on the surfaces of the esophageal mouthparts. Once acquired, viruses may persist in transmissible form in starved Longidorus for up to 12 weeks, in Xiphinema for about a year, and for much more than a year in Trichodorus.

Release: The retained virus must be released from the site of retention in the nematode. This is thought to occur as a result of nematode-gland secretions that wash over the virus particles during feeding. Release of the virus particles is thought to occur by a change in pH caused by saliva flow when the nematode commences feeding on a new plant.

Transfer and Establishment: In the transfer and establishment phases, the virus particles are placed in the healthy plant cell and start replicating and causing infection. There is specificity in the relationships between nematodes and the viruses they transmit with often an

apparent unique association between the virus isolate and the vector species. There are some cases of different virus isolates sharing the same vector species or, conversely, one particular virus isolate being transmitted by several nematode species. There are 13 trichodorid species known to be tobravirus vectors, but only one or two of these transmits each tobravirus.

There is a high degree of specificity in this association, in that particular virus isolates may be transmitted only by certain nematode species **(Ploeg *et al.,* 1992),** and the specificity may be expressed either as an inability of a certain virus to be retained within the nematode mouthparts or, in at least one example, an inability of retained virus to be released from the nematode oesophagus during feeding.

List of diseases transmitted through Nematodes

Disease	Causal organism	vector
Arabis mosaic	Arabis mosaic virus (ArMV)	Nematode *Xiphinema diversicaudatum*
Grapevine fan leaf	Grapevine fan leaf virus (GFLV)	Nematode *Xiphinema index*
Pea early browning	Pea early browning virus (PEBV)	Nematode *Trichodorus sp*
Pepper ring spot	Pepper ring spot virus (PepRSV)	Nematode *Trichodorus sp*
Pine wilt disease	Pine wood nematode (*Bursaphelenchus xylophilus*, Aphelenchoididae)	*Monochamus* genus (Cerambycidae)
Raspberry ring spot	Raspberry ring spot virus (RRSV)	Nematodes *Longidorus sp*
Red ring of coconut	Red ring nematode (RRN; *Bursaphelenchus cocophilus*, Aphelenchoididae),	Red palm weevil *Rhynchophorus palmarum* (Curculionidae)
Strawberry latent ring spot	Strawberry latent ring spot virus (SLRSV)	Nematode *Xiphinema diversicaudatum* *Xiphinema coxi*
Tobacco rattle	Tobacco rattle virus (TRV)	Nematode *Paratrichodorus pachydermus*
Tobacco ring spot	Tobacco ring spot virus (TRSV)	Nematodes *Xiphinema americanum,*
Tomato black ring	Tomato black ring virus (TBRV)	Nematode *Longidorus attenuatus*
Tomato ring spot	Tomato ring spot virus (ToRSV)	Nematode *Xiphinema sp*

Chapter -13
Vector transmission efficiency

Vector transmission efficiency of plant viruses refers to how effectively a vector, such as an insect, can acquire a virus from an infected plant and then transmit it to a healthy plant, leading to infection.

Experimental calculation of Transmission efficiency:

The basic process includes

- **Virus-free vectors:** vectors (e.g. insects) are initially virus free before being exposed to infected plants to acquire the virus
- **Source Plant Exposure:** Virus-free vectors are allowed to feed on infected source plants for varying durations (acquisition access period, AAP). The efficiency is the probability of successful virus acquisition by the vector over time.
- After incubation period, testing the recipient plants for infection. There are currently two main methods for virus diagnosis
    - **ELISA (Enzyme linked immunosorbent assay):** A widely used technique to detect the presence of viral antigens in plant tissues or vectors, allowing for high-throughput analysis.
    - **RT-PCR or PCR:** Used to amplify and detect viral nucleic acids within the vector or plant.
- **Target Plant Exposure:** Virus-carrying vectors are exposed to healthy plants for different periods (inoculation access period, IAP). Efficiency is determined by the number of plants infected after these periods.
- **Calculating Efficiency:** The basic measure is the percentage of plants that become infected by the virus.

$$Transmission\ efficiency\% = \frac{Number\ of\ \ plants\ \ infected\ with\ virus}{Total\ number\ of\ plants\ exposed\ to\ vectors} \times 100$$

Factors Influencing Efficiency

- **Vector Diversity:** Different populations of the same aphid species, for example, can show varying efficiencies due to genetic differences or endo-symbiont variation.
- **Virus Strain:** Different strains of the same virus can be transmitted with different efficiencies by the same vector.

- **Vector Behaviour:** The duration of salivation or probing by the vector on a plant cell can dramatically affect transmission rates.
- **Plant Resistance:** The plant's susceptibility to the virus can influence the overall success of transmission.
- **Environmental Factors:** Controlled conditions, such as those found in climatic chambers, are used to ensure consistent and reproducible results.

Applications of Efficiency Estimation

- **Understanding Virus Epidemiology:** Access period experiments help estimate crucial epidemiological parameters, such as the vector's retention period for the virus.
- **Studying Viral Evolution:** Efficiency differences can highlight selective pressures on viral populations, showing that only variants with high transmission efficiency by specific vectors persist.
- **Developing Disease Management Strategies:** Understanding efficiency helps predict disease spread and design effective control measures by targeting specific vector-virus interactions.

Chapter-14
General Symptoms of viral diseases

Plant viruses cause a wide variety of symptoms. These symptoms can be local to the infection site or systemic spreading throughout the plant. Major symptoms are of following.

1. **Mosaic leaf pattern**- intermingling patterns of green and light green or pale green or yellowish in colouron the leaves is known as 'mosaic'.
   Eg: maize mosaic
   Wheat streak mosaic
   Ragi mosaic
   Yellow vein mosaic of mung, urd, bhendi
2. **Crinkled leaves**- the surface of leaves is not uniform and is with undulations. Leaves are thick and brittle and remain green till harvest.
3. **Yellowed leaves or chlorosis**-yellowing of normally green tissues due to chlorophyll destruction or failure chlorophyll formation is called as 'chlorosis.
4. **Plant stunting-** disease affected plants are being shorter than healthy plants
   Eg: corn stunt
5. **Vein clearing**- yellowing of veins or clearing of the tissues in or immediately adjacent to the veins is called 'vein clearing'.
   Eg: vein clearing of bhendi
   Cardamom vein clearing
6. **Vein banding**- the tissues along the veins are dark green than the tissues between the veins is called 'vein banding'.
   Eg: goose berry vein banding
7. **Leaf curling**- the leaves curl from the margins backward bringing the centre of lamina.
   Eg: leaf curl in chilli,
   i. Tomato,
   ii. Tobacco,
   iii. Papaya,
   iv. Brinjal etc.
8. **Bunchy tops**- in bunchy top, extreme stunting of the plant with bunching of small, erect and brittle leaves at the crown of plants is seen.
   Eg: Banana bunchytop virus (BBTV)
9. **Ring spots-** it is charecterised by yellowish or necrotic rings surrounding green tissue. It appears on fruits and leaves.
   Eg: Papaya ringspot virus,
   Coffee ring spot virus,

Prunus necrotic ring spot virus

10. **Stripe** – it is charecterised by elongated or areas of pale green to yellow or white, of indefinite length, on leaves with parallel venation or on stems.
    Eg: rice stripe virus
    Maize stripe virus
    Peanut stripe virus
11. **Streak** – development of chlorotic streaks on leaves and which later become necrotic.
    Eg: wheat streak mosaic virus
    Maize streak virus
    Banana streak virus disease
12. **Enations** – enations are hair like or leaf like outgrowths from the veins on the undersurface of the leaves diseased by the different viruses.
    Eg: pea enation mosaic
    Okra enation leaf curl disease
    Dolichos enation mosaic
13. **Necrosis**- necrosis (death of cells) of the tissues in the growing shoots due to virus infection.
    Eg: peanut bud necrosis virus (PBNV)
    Tomato necrotic ring spot
    Peanut stem necrosis
14. **Dwarfing** – a decrease in overall size without alteration of the proportions between the parts of the plant is known as 'dwarfing'
    Eg: rice dwarf virus
    Barley yellow dwarf
    Maize rough dwarf
15. **Rosette**- shortening of internodeswith reduction in leaf size is seen. Plants show stunting with bushy appearance.
    Eg: peanut rosette virus
    Rose rosette virus
16. **Swollen shoot:** characterized by mosaic and shedding of leaves, dwarfing and mottling of pods, and especially by shortening and swelling of the internodes of the stem and of the roots
    Eg: cacao swollen shoot virus
17. **Distortion (witches broom)**: It is a common symptom of virus diseases. This symptom is characterized by the alteration in the symmetry of leaf arrangement, crinkling of edges of the leaf, leaf rolling and leaf resetting, sometimes the leaves become reduced in size, at the internodes and there is production of a cluster of distorted shoots.
    e.g., leaf roll of potato, leaf curl of papaya, leaf curl of tomato etc.

Chapter-15
Integrated management practices of insect vectors of plant pathogens

For the management of various types of plant diseases transmitted by insects, integrated strategies should be adopted to manage the vectors. For any successful vector management programme, all the tactics should be combined carefully. For this strategy to be effective, identification of the plant pathogens and insect vectors is very important along with knowledge of their biology.

Viral diseases cannot be controlled once the plant is infected. Therefore, every effort should be made to prevent introduction of viral diseases into the field. Infected plants should be removed immediately to prevent spread of the pathogens.

Insect vectors are much more dangerous and difficult to manage because small population of vector can spread the pathogen in whole of the field, particularly the plant viruses. Control options for insect vectors are quite different for vectors than insect pests because insecticide may increase rather than decrease the spread or incidence of virus diseases. Parasitoids, predators and pathogens seem neither as effective nor as promising for the control of vectors because economic threshold densities for vector species are much lower than those that would be expected to direct damage to the crop.

Management strategies for insect vectors

Some of the important components of such a strategy should involve selection of healthy seed, cultural practices, biological measures, resistant varieties and use of chemicals among others. Various strategies employed to prevent and reduce the intensity of plant viruses are discussed.

Quarantine measures and pathogen free seed/planting material

These are imposed to prevent the entry of new pathogens from the area of its prevalence to the new area and are used to check the long distance spread of plant pathogens. Viruses are introduced into new areas through bud wood scions root stocks, trees, shrubs, tubers, rhizomes, corms, bulb, etc. of vegetatively cultivated plants. Tristeza virus was not present in countries like USA, China and South Africa which were cultivating citrus on large scale because of two reasons viz. resistant/tolerant varieties and absence of efficient vectors. The disease spread to South Africa in 1930 when susceptible root stock was imported. Certification schemes for potato have been introduced to produce virus (Potato leaf roll and PVY) free seed in many countries. Punjab is producing potato seed free of virus by following seed plot technique, taking into consideration the arrival of aphid vectors in state. To check the presence of virus in the planting material, virus indexing can be done.

Many viruses are seed borne and carried by planting material. The use of certified seeds/planting material is necessary to restrict the initial build-up of infection in the field. So always use virus free seed or the planting material so that there is no virus source available to the areal vector to spread the pathogen. Once the virus source is eliminated, the vector would not be able to acquire the virus. The yield of lettuce was increased in the Salinas valley area of California by cultivating the lettuce mosaic virus free seed **(Kimble *et al.,* 1975)**. Cultivation of certified seeds always gives good dividends, such as seed certification schemes against BSMV have been credited with avoiding millions of dollars in losses due to this disease in barley crops in USA **(Carrol, 1983)**. It can be achieved through different means like thermotherapy, chemotherapy, cryotherapy and electrotherapy. Besides, virus free plants through tissue culture technique can be produced.

Host plant resistance

Host-plant resistance that prevents feeding or repels insects can prevent transmission of virus spread by vector feeding. Resistance to the viruses may be the only means of management in some cases; an example of it is sugarcane mosaic virus. Sugar cane is propagated vegetatively, so the virus is propagated with the crop in the same field for several years of production, and even if clean planting stock could be found, there is no possibility for an area wide crop-free (and virus-free) period. The virus is transmitted by transient winged aphids, including species that do not necessarily colonize the sugarcane crop, so pesticide application is not effective. Fortunately, success has been achieved with mosaic resistant cultivars **(Sarwar *et al.,* 2009; Sarwar, 2012, 2013)**.

Our ability to help growers to control vector-borne diseases depends on our ability to generate pathogen- and/or disease- resistant crops by traditional or synthetic approaches and to block pathogen transmission by insect vectors **(Heck, 2018)**. Growing resistant and tolerant verities is another effective way of managing vectors and vector-transmitted diseases.

It is one of the most important tactics by which the population of vector can be reduced on insect resistant cultivar and the pathogen resistant cultivar will prevent the availability of virus sources from the field. To be successful, always depend on resistant varieties as it is cheap and most reliable measure. Resistance to the pathogen may be the only means of management in some cases. An example is sugarcane mosaic virus. Non-preference should perhaps be the most effective form of resistance to the vector for control of non-persistent type viruses, whereas antibiosis may be effective for persistent types of viruses. It is desirable to breed varieties resistance to vector. Resistant varieties are the most effective source of insect vector management which ultimately resist viruses. A sugarbeet germplasm line, CR09-1 resistant to beet necrotic yellow vein virus was developed and registered in USA **(Lewellen, 2004)**. Genetically modified plants can be the best solution to tackle the problems of insect vectors of plant pathogens.

Paratransgenesis

Paratransgenesis is a novel approach for genetic manipulation of host symbiotic microorganisms to achieve an array of objectives ranging from disease eradication to pest control. Such arthropods containing these transformed microorganisms are called paratransgenic. Genetic engineering of gut symbiont provides a new form of transgenic arthropod that has been termed paratransgenesis **(Durvsula *et al*., 1997)**. Genetic manipulation that can be cultured outside their host is easier to achieve than transformations of the arthropod itself. This novel approach has been exploited to modify infectious pathogen mediated diseases in pierce disease of grapes, Fiji leaf gall in sugarcane etc.

Cultural control measures

These are most important measures to tackle the problems of vector borne viruses and to minimize the damage. Several cultural practices have proved to be helpful in reducing the incidence of vectors and vector borne diseases such as selection of healthy seed or planting materials, clean cultivation, isolation, Timing of planting and harvesting, plant density, nutrient management or manuring, destruction of host plants of vectors, mixed and barrier crops, crop rotation, destruction of alternate hosts.

Selection of healthy seed or planting materials

The selection of seed for planting should be healthy. So, resistant varieties should be used for crop production. The susceptible varieties should never be cultivated. Crop cultivars resistant to major pests which acts as vectors in rice, wheat, maize and sorghum, sugarcane and limited extent of pulse and oil seed crops. Some important resistant varieties of pests which acts as a vectors are given below

Pest	Resistant variety
Brown plant hopper	Mudgo, swarnalata, rathu heenati, IR 26, IR 36, IR 64, IR 72, PY 3, CO42, ADT 35, ADT 37, Asha, Aruna, Kanaka, Karthika, krishnaveni.
Green leaf hopper	IR 50, IR 54, IR 64, PY 3, White ponni, IR 46, IR 38, IR 66
Zig zag leaf hopper	IR 56
Chilli thrips	Pusa jwala
Onion thrips	Pusa red, Bombay white
Cotto jassid	Khandwa, Badnawar, MCU 5, Krishna, Mahalakshmi, Sujay
Whitefly in cotton	Amravati, Kanchan, supriya, LK 861
Mustard aphid	Pusa jai kisan, pusa kalyani, Laha 101, RLM 84

Clean cultivation

The elimination of plant debris on the soil surface, in which many pests find shelter for hibernation such as flea beetles, whiteflies of brassica and also reduce the insect infestation.

Isolation

Growing of virus susceptible crops in isolation is a useful practice to avoid the risk of viral infection. Increasing the distance between the virus source and crop may be simplest and effective way of minimizing the number of viruliferous insects that can find the crop. Therefore, efforts should be made to grow the crop in a site where the vectors are unable to infect the crop. So, minimum effective isolation distance can be estimated from quantification of disease gradient **(Thresh, 1976)**. To protect the potato crop from potato viruses in India, the crop is grown in hilly areas where aphids are not present for most of the crop season. This technique is being followed to produce virus free (Potato virus X, Potato virus Y, Potato leaf roll virus) seed in potato.

Timing of planting and harvesting

Adjusting planting dates can minimize crop exposure to vectored pathogens.There are number of instances in which the time of planting or harvesting has been shown to influence the incidence of viral diseases. To avoid invasion of crop by efficient vectors, the sowing and harvesting dates are altered. In India, successful seed production was there in Shimla where aphid population was not there which could infect the tuber during the crop season. Seed plot technique is followed for raising potato seed crop in Punjab free from viral infection of potato leaf roll and other aphid borne viruses.

- Early sowing in mustard to protect crop from mustard aphid.
- **Harpaz (1982)** controlled the incidence of maize rough dwarf virus by altering the planting dates of maize in Israel.
- Late sowing or delay in planting (October instead of September) reduced the barley yellow dwarf (BYDV) in cereals in Austria by discouraging the aphid population at that time.

Plant density

Brown plant hopper (*Nilaparvata lugens*) favours dark and humid condition and more abundant at the base of paddy plants when they closely planted. This practice is being exploited to manage viral infection in rice by reducing vector. Adults of many aphid spp. seem to preferably exploit young plants spaced out and grown against bare soil as compared to close spaced plants. So, increase in crop intensity may reduce aphid colonization. **Reddy *et al.* (1983)** observed early planting and increased plant density reduce the incidence of groundnut bud necrosis virus in groundnut. Plants possessing better growth with succulent foliage are preferred for feeding of insect vectors, thus likely to suffer more from viral infections.

Nutrient management or manuring

It is an established fact that healthy plants are less attacked by pests there are 20 essential plant elements which are needed for the growth and development of the plants. Out of these, N. P and K are major nutrients, In general, high nitrogen supply results in increased tissue softness,

increase in chlorophyll content and water content as carbohydrates making the plant more susceptible to attack by insects like aphids, leafhoppers, mites, thrips and leaf-miners. Presence of higher level of P and K makes the plant less susceptible for aphids. Thus, manipulation of these major nutrients can be used to manage the insect population under control. Higher proportion of N: P: K (80:40:30) showed higher population of mustard aphid whereas 40:80:40 ratio reduced aphid infestation. Similarly, high N: P: K (225:90:45) increased population of cabbage aphid on cauliflower. Enhancement of succulent cotton growth through nitrogen fertilisation causes severe attack of the cotton aphid (Aphis gossypii). The excess of nitrogen fertiliser also renders paddy plants more vulnerable to the infestation of brown plant hopper (*Nilaparvata lugens*) **(Singh, 2006)**.

Infection of tobacco leaf curl virus is more in a robust crop when fertilized with excessive nitrogen. The reduction in the dose of nitrogen in onion crop reduced the population of thrips **(Buckland *et al.*, 2013)**.

Destruction of alternate host plants of vector

The plants and weed hosts are known to serve as reservoir for viruses and these plants become primary sources of infection. Vectors often breed on other crops or wild hosts that are also sources of virus. So, removal of these can minimize the initial inoculum. In annual crops alate vectors initiate/spread the virus and peak of virus spread coincide with peak of migrant alate vector. The distance of crop from alternate host from which alate vectors are to be set off and the flight behaviour of the vector which leads them to find the crop plant? Groundnut mosaic virus is epidemic in some South African, the rouging of diseased plants from new planting sites after two months of planting resulted in control of virus. Banana bunchy top virus can be successfully controlled by rouging the diseased plants. The rogueing of diseased plants in cassava for cassava mosaic virus is being practiced regularly to mitigate the disease severity **(Thresh and Cooter, 2005)**.

During this period attention was given to prevent sugarbeets being left in the ground and cooperative efforts were made to destroy the weeds **(Duffus, 1983)**.

Mixed crops

Mixed crops are always helpful in preventing the secondary spread of vector borne pathogens. This practice is common in minimizing the incidence of non-persistent plant viruses. As the viruliferous vector particularly aphids when feed for little longer period on the non-host inter crop loose the virus. It has been shown that infestation of Aphis gossypii is less in pure crops of green gram, black gram and sunflower as compared to main crop in combinations with cotton.

Intercropping

Intercropping of onion and garlic with tomato decreased the level of thrips infestation by 79-86 and 81-85 per cent, respectively **(Afifi and Haydar, 1990)**. Barrier crops are likely to be more effective in protecting plants from non-persistent type around the main crop. Sunflower acts as barrier crop in tomato, celery against vein banding and potato virus Y. Further sunflower, sesame, pearl millet reduced the incidence of cucumber mosaic virus in chilli when used as

barrier crop in Punjab **(Deol and Rataul, 1978)**. By using barley as a barrier crop along with application of albolineum oil give complete control of tulip breaking virus **(Harrison *et al.,* 1976)**. Incidence of yellow vein mosaic of okra is reduced by intercropping with soybean. Similarly, intercropping of tomato with coriander reduces the incidence of tomato leaf curl virus in tomato.

Trap crops

Growing maize as barrier crop on borders and mulching with paddy straw reduced the incidence of mungbean yellow mosaic virus **(Mukhopadhyay *et al.,* 1994)**. Maize and sorghum are grown as barrier crops in pepper for cucumber mosaic virus and potato virus Y in Spain **(Fereres, 2000)**. Maize and wheat were used as barrier crop in potato to trap population of aphids for potato viruses in seed production plots in Africa **(Schroder and Kruger, 2014)**.

Crop rotation

Continuous cultivation of paddy crop in the same locality or practice of rationing of sugarcane provides a continuous supply of food and shelter to the pest for ceaseless breeding. This results in a quick buildup of the population of pest. Control of tobacco leaf curl virus was obtained by keeping the field fallow for three weeks after the harvesting of tobacco crop. Whitefly vectors could not acquire the virus. Rice tungro virus is serious in South India where rice is grown after rice. The volunteer wheat provides a 'green bridge' for the viruses and their vectors between harvest of one crop and emergence of the next one **(Halbert, 2011)**. Sugarbeet growers in California broke the infection cycle of virus yellows by introducing a beet free period in the field. To control these diseases crop rotations must be followed. By establishing crop free period (mid-June to mid-July) in Arvara valley of Israel, the attacks of aphid and whitefly transmitted viruses in vegetables was reduced **(Ucko *et al.,* 1998)**.

Mechanical control measures

These methods of insect control is labour intensive and can not be applied commercially but are useful either in small scale cultivation on onset of infestation. Use of insect traps such as light traps and sticky traps, protective cover and mulches can be controlled insect vectors.

Insect traps

Traps are used for survey, surveillance and control purposes. Various types of light traps and sticky traps (yellow, blue etc.,) are used for controlling of insect vectors. The serious pests of paddy such as *Nephotettix* spp. and *Orseola oryzae* which acts as vectors can be trapped by light traps and killed.

Aphids, Thrips and whiteflies prefer Yellow Colour. Yellow colour is painted on the boxes and sticky material like Castor oil/vaseline is smeared on the Surface. These insects are attracted to yellow colour and trapped on the sticky material. **Birch *et al.,* (2004)** used white sticky traps, specific flower volatile attractants, resistant verities, synergism with natural enemies and chemicals to control raspberry beetle.

Survey and surveillance traps such as Sticky traps are working so well that they are now a standard practice for the control of aphids and some other flies during the day acts as vectors for many viruses like potato viruses and cucumber mosaic viruses. The attraction of winged aphids to yellow has been utilized for many years in the yellow water pan traps or yellow sticky traps to monitor aphid populations. Sticky traps are used for direct vector control. This is a standard practice for the control of potato virus and CMV in peppers in Israel.

Mulches

Growing the crop under protected cultivation we can keep the vectors away from the crop. By covering tomato nursery with nylon nets for 3-4 weeks following by sprays of pesticide delayed the tomato leaf curl incidence for 3-5 weeks. Many crops are grown under green houses to control the vectors of pathogens. Enhanced management in flower bulb production is achieved through the use of reflective mulches in the virus control **(Wilson, 1999)**. Mulching of tomato and cucumber field with saw dust or yellow polythene sheets reduced the incidence of cucumber yellow vein virus and tomato yellow leaf curl virus and the population of the whitefly vector **(Cohen and Madjar, 1978)**. Combined use of mulching and pre-sprouting had a synergistic effect on reduction of PVY incidence **(Saucke and Doring, 2005)**.

Chemical control

Chemical control of vectors will limit spread of vectored plant pathogens if two conditions are met. First, the vector being controlled must be a colonizer of the crop being treated. Some plant viruses are transmitted by transient flying insects. In these cases, chemical control has a poor record.

Second, most of the spread must come from within the treated area (secondary spread). For the most part, insecticides simply prevent the buildup of populations of insects within a treated area.

Pesticide treatment has a good track record for control of certain *luteovirus* diseases such as potato leafroll and barley yellow dwarf, spread by colonizing aphids. **(Halbert, 2011)**

Chemicals are used against the vectors of plant pathogens to manage plant viruses since long. Understanding the transmission process and interaction between insects and their chemical environment elucidates areas of the epidemiological cycle at which pesticide oriented control strategies could be targeted most effectively. To apply this, it is always desirable to know the complete virus vector relationship indicating whether the virus is of non-circulative, or semi-persistent or persistent category. **Perring *et al.*, (1999)** observed that of the reported successes controlling virus spread using insecticides, a high percentage (94 of 119 cases) were persistently and semi-persistently transmitted viruses.

The control of insect vectors by application of insecticides appears to be a difficult task as few survivors would be able to transmit the disease. The timely application of insecticides restricts the spread of the disease by reducing the vector population. Several systemic and non-systemic insecticides have been reported to control the insect vectors. Although different chemicals are readily availability, but use of insecticides is not a good idea as far as management

of non-persistent category of plant viruses is concerned. The non-persistent and semi-persistent type viruses require short inoculation period. The use of insecticides will increase the incidence of viruses because of increased movement of vectors and increase in probing by disturbed and restless vectors of stylet borne viruses. Also these chemicals kill the natural enemies of vectors. As a result the population of vector will increase and will cause extensive damage. However, viruses of persistent (propagative) and semi- persistent (circulative) categories are effectively controlled with insecticides.

- Various chemicals can be used to manage insect vectors like chemicals of plant origin, antifeedants, repellents, pheromones, baits, mineral oils and insecticides.
- The use of biopesticides such as microbial and plant extracts is an eco-friendly approach to manage the vectors and vectors borne diseases. Many chemicals have been shown to reduce the rates of feeding, setting or reproduction of hemipterans e.g. Dodeconoic acid and polygodia for *M. persicae* **(Gibson *et al.*, 1982).**
- Many pesticides of plant origin are used to control plant viruses. Azadirachtin is used to tackle Barley yellow dwarf virus transmitted by aphids **(West and Mordue, 1992)**.
- Minerals oils are highly effective against non-persistent viruses as they cause physical blockage of air exchange and act as physiological poison, reduce probing/feeding of vector, alter vector behavior and locomotion, impede acquisition/infection process as they inhibit virus during probing through stylet contacts and may affect plant physiology and landing of vector **(Fereres and Moreno, 2009)**.

It is possible to eliminate arthropod vectors or considerably decrease their numbers either with chemicals or any other means. The threshold for vector is extremely low, in most cases single insect is sufficient to spread virus. In case of vectors where viruses persist throughout the life of vector, it becomes more cumbersome to manage such vectors

Biological control

Sometimes natural enemies play good role in reducing numbers of harmful insects acting as vector of plant pathogens however low level of population of insect vector could prove harmful as only one individual is capable to spread the disease in the field. The maintenance of low population of insect vector could be dangerous. Biological control in simpler island ecosystems may have a better chance to work than in more complex settings. For example, the introduction of psyllid parasitoids into Reunion Island dramatically reduced the transmission of the bacteria that causes citrus greening disease. However, the same parasitoids are present in Vietnam, and citrus greening disease is a major limiting factor in citrus production there. *Encarsia formosa* is a parasitoid used worldwide for the biological control of whiteflies on vegetables and ornamental plants grown in greenhouses **(Hoddle *et al*., 1998).**

List of Predators, parasitoids and Entomopathogens of insect vectors

Predator	Target insect
Australian lady bird beetle (* P) (*Cryptolaemus montrouzieri*)	Mealybugs
Lady bird beetle (* P)	Aphids, mealybugs

(*Coccinella septumpunctata*)	
Green lace wing (* P) (*Chrysoperla carnea*)	Aphids, mites, psyllids, whiteflies, black flies
Syrphid flies/ Hover flies (* P)	Aphids, Thrips
Anthocorid bugs (* P)	Aphids, Thrips
Lacewing (* P) (*Mallada boninensis*)	Aphids, psyllids
Bug (*Cyrtorhinus lividipennis*)	Brown plant hopper (*Nilaparvata lugens*) and leaf hoppers
Wolf spider (*Lycosa pseudoannulata*)	Brown plant hopper (*Nilaparvata lugens*)
Encarsia Formosa (*PS)	Whiteflies
Verticillium lecanii (*EPF)	Aphids, Thrips, whiteflies
Pandora delphacis(*EPF)	Brown plant hopper Green leaf hopper
Pandora neoaphidis (*EPF)	Aphids
Aschersonia aleyrodis (*EPF)	whitefly

*P= predator; *PS= Parasitoid; * EPF= Entomopathogenic fungi

Practical

Exercise -1
Preparation of PDA Media

Principle:

Potato dextrose agar media is composed of dehydrated potato infusion and dextrose that encourage luxuriant fungal growth.

Potato dextrose agar medium is commonly used for isolation of fungus as well as its maintenance.

Composition:

Potato- 200 grams.
Dextrose-20 grams (Carbohydrate source)
Agar-Agar- 15 grams (solidifying agent)

Procedure:

1. Wash 200 grams of potato, peel of the skin and slices into small pieces
2. Cook the sliced potatoes in 1000 ml of distilled water for 30 min in an open vessel
3. Filter the potato infusion through muslin cloth.
4. Mix 15 grams of agar in potato infusion and stir well
5. Add 20 grams of dextrose to potato infusion and check the pH of the medium by using pH indicator paper.
6. Pour the medium into sterilized conical flasks and plug with non-absorbent cotton.
7. Arranged the conical flask in wire basket
8. Sterilized in an autoclave at 15 psi (121^{o}C temperature) Pressure for 15 min's
9. Take out the sterilized conical flask after rereleasing the steam
10. After solidifying, the conical flasks are arranged in wire basket and stored in clean room for further use

Note: Procedure to check pH-

- Stir the medium with glass rod and take a small bit of pH indicator paper and dip in the medium. If the pH is above 7, add few drops of HCL (Hydrochloric Acid) stir well and again check pH for neutral. If the pH of the medium is below 7, add few drops of NaOH (sodium Hydroxide) to increase the pH to 7.

- Sometimes bacterial colonies develop on the agar and inhibit fungal growth making identification difficult. This can be overcome by adding an antibiotic such as streptomycin (500ppm) to the autoclaved agar medium after it cools to 50-55^{0}C.

Uses:

1. PDA is used for the detection of the yeast and moulds.

Preparing form Commercial medium powder:

20 grams of dextrose	39 gm.
4 grams of potato starch	
15 grams of agar	
Distilled water	1 lit.

Exercise -2

Preparation of Nutrient agar Media

Nutrient agar is a culture medium used to grow bacteria

Composition:

- Peptone-5.0gm
- Beef extract-1.5gm (water soluble and contribute vitamins, carbohydrates, amino acids, nitrogen, and salts essential for growth)
- Yeast extract-1.5gm
- Agar- agar -15gm (solidifying agent and which provides a good platform for the colony growth of the pathogen)
- Sodium chloride-5.0 gm. (supplies essential electrolytes for transport and osmotic balance)
- Distilled water -1000 ml
- P^H range -7.0-7.2

Procedure:

1. Weigh the components of nutrient media.
2. Add distilled water and stir well with the help of glass rod.
3. Pour the solution into conical flasks, leaving some head space and plugged with non-absorbent cotton.
4. Sterilize in an autoclave at 15psi (121^0C) for 15 minutes.
5. Let the conical flasks cool in water bath to 55^0C.
6. Pour the molten medium into petri dishes to a depth of about 5mm.
7. Let the medium set, and then dry in a laminar flow chamber.
8. Store the petri plates in the fridge, inverted and sealed in plastic bags.

Exercise-3

Isolation and identification of fungal pathogens carried by insect vectors

Many insects transmit bacterial and fungal spores passively by feeding in or walking through an infected plant area that has on its surface plant pathogenic bacteria or fungal spores as a result of the infection. The bacteria and spores are often sticky, cling to the insect as it moves about, and are carried by it to other plants or parts of the same plant where they may start a new infection.

Some insects transmit certain bacteria, fungi, and viruses by feeding on infected plant tissues and carrying the pathogen on their mouthparts as they visit and feed on other plants or plant parts.

Requirements:

Insect vector
PDA media
Dissection kit
Laminar air flow chamber
BOD incubator
Sterilized petri plates
Hot air oven
Spirit lamp

Isolation procedure:

1. Place the sterilized petri plates in laminar air flow chamber
2. Pour the melted PDA media into petri dishes.
3. Let the petri plates solidify.
4. Dissect the insect vector under aseptic condition in laminar air flow chamber to avoid contamination.
5. Place the dissected insect in the middle of the petri plates.
6. Close the lid of petri plates carefully.
7. Seal the petri plates with Para film to avoid the entry of other pathogens.
8. Place the isolated petri plates in BOD incubator at the temperature of 27-32 ºC for proper fungal growth.

Exercise-4

Isolation and identification of bacterial pathogens carried by insect vectors

Requirements:

Insect vector
Nutrient agar (NA) media
Dissection kit
Laminar air flow chamber
BOD incubator
Sterilized petri plates
Hot air oven
Spirit lamp

Isolation procedure:

1. Place the sterilized petri plates in laminar air flow chamber
2. Pour the melted nutrient agar media into petri dishes.
3. Let the petri plates solidify.
4. Dissect the insect vector under aseptic condition in laminar air flow chamber to avoid contamination.
5. Place the dissected insect in the middle of the petri plates.
6. Close the lid of petri plates carefully.
7. Seal the petri plates with Para film to avoid the entry of other pathogens.
8. Place the isolated petri plates in BOD incubator at the temperature of 27-32^{0}C for proper bacterial growth.

Exercise -5
To study about the Virus vector relationship

Virus vector relationship based on site of retention of the virus in vector

Kennedy *et al.,* (1962) coined the virus- vector relationships as follows

1. **Non- circulative** (**Stylet borne or non-persistent**) - The vector has to feed freshly whenever it transmits a virus *i.e.,* it loses its infectivity after single transmission. The virus carried in the stylets and they don't reach the midgut.
   Ex: - .Aphids
2. **Circulative** (**Persistent or non-stylet borne**)-The vector remains to be viruliferous for rest of its life i.e. The infectivity lasts until its death and no need to feed regularly whenever it transmits the virus. Viruses are not carried out in the stylets and they reach midgut.
   Ex: - Leaf hoppers, whiteflies

3. **Propagative**- some viruses which can multiply in the vectors midgut.
   Ex: - Some leafhoppers, Thrips

Virus vector relationship based on virus retention time by the vector

Watson and Roberts (1939) gave the basic concepts of virus vector relationship on the basis of the method of transmission and persistence (Retention time) in the vector, viruses may be classified into three categories.

a. Non-persistent (stylet borne)

b. Persistent

c. Semi persistent **(Sylvester, 1958)**

Particulars	Non persistent (stylet borne)	Semi persistent (stylet borne)	Persistent (Circulative /Non propagative)
Mechanical transmission	Yes	No	No
Tissue of virus acquisition	Epidermis and parenchyma	Mesophyll, phloem and parenchyma	Mostly phloem
Acquisition period	Low (from seconds to minutes)	More (Minutes to hours)	More (hours to days)
Latent period	Not required	Not required	Required (Hours-Days-Weeks)
Period for which vector remains infective (Retention time) or (Persistent)	Usually less than 4 hours but can be up to 10 hrs.	10-100hrs	More than 100 hrs.
Multiplication of virus in vector	No	No	Yes, in some vectors
Retention of virus through moulting (Transstadial transmission)	No	No	Yes
Sequential Inoculation	Low (Seconds to minutes)	More (Seconds to minutes)	More (Minutes to hours)
Virus vector specificity	Low	Intermediate	High
Location of virus in vector	Externally or near mouthparts	Near the junction of Stylet and tip	Internally in Haemolymph
Vectors	Aphids and Mites	Aphids, Beetles, Leaf hoppers, Mealy bugs, Whiteflies	Aphids, Beetles, Leaf hoppers, Mites, Thrips, Nematodes, Bugs, Fungi, Whiteflies
Symptoms	Mosaic type of diseases	Yellowing	Leaf roll and yellowing
Examples	Bean yellow mosaic Soybean and cowpea mosaic virus	Cauliflower mosaic virus and beet yellow virus	Potato leaf roll and citrus Tristeza virus

Acquisition period: It is the time for which an initially virus free vector is allowed to access to a virus source *i.e.,* virus to infected plant materials.

Latent period: the time between acquiring the virus by the vector and the ability to transmit it.

Inoculation period: It is the time for a virus carrying vector is allowed access to a virus free plant and could feed on it

Retention/ Persistence: It is the time for which a vector remains infective even after leaving a virus source.

Exercise-6

To study about General Symptoms of viral diseases

Plant viruses cause a wide variety of symptoms. These symptoms can be local to the infection site or systemic spreading throughout the plant. Major symptoms are of following.

1. **Mosaic leaf pattern**- intermingling patterns of green and light green or pale green or yellowish in colour on the leaves is known as 'mosaic'.
   Eg: maize mosaic
   Wheat streak mosaic
   Ragi mosaic
   Yellow vein mosaic of mung, urd, bhendi
2. **Crinkled leaves**- the surface of leaves is not uniform and is with undulations. Leaves are thick and brittle and remain green till harvest.
3. **Yellowed leaves or chlorosis**-yellowing of normally green tissues due to chlorophyll destruction or failure chlorophyll formation is called as 'chlorosis.
4. **Plant stunting-** disease affected plants are being shorter than healthy plants
   Eg: corn stunt
5. **Vein clearing**- yellowing of veins or clearing of the tissues in or immediately adjacent to the veins is called 'vein clearing'.
   Eg: vein clearing of bhendi
   Cardamom vein clearing
6. **Vein banding**- the tissues along the veins are dark green than the tissues between the veins is called 'vein banding'.
   Eg: goose berry vein banding
7. **Leaf curling**- the leaves curl from the margins backward bringing the centre of lamina.
   Eg: leaf curl in chilli,
   Tomato,
   Tobacco,
   Papaya,
   Brinjal etc.
8. **Bunchy tops**- in bunchytop, extreme stunting of the plant with bunching of small, erect and brittle leaves at the crown of plants is seen.
   Eg: Banana bunchytop virus (BBTV)
9. **Ring spots-** it is charecterised by yellowish or necrotic rings surrounding green tissue. It appears on fruits and leaves.

Eg: Papaya ringspot virus,
Coffee ring spot virus,
Prunus necrotic ring spot virus

10. **Stripe** – it is characterised by elongated or areas of pale green to yellow or white, of indefinite length, on leaves with parallel venation or on stems.
    Eg: rice stripe virus
    Maize stripe virus
    Peanut stripe virus
11. **Streak** – development of chlorotic streaks on leaves and which later become necrotic.
    Eg: wheat streak mosaic virus
    Maize streak virus
    Banana streak virus disease
12. **Enations** – enations are hair like or leaf like outgrowths from the veins on the undersurface of the leaves diseased by the different viruses.
    Eg: pea enation mosaic
    Okra enation leaf curl disease
    Dolichos enation mosaic
13. **Necrosis**- necrosis (death of cells) of the tissues in the growing shoots due to virus infection.
    Eg: peanut bud necrosis virus (PBNV)
    Tomato necrotic ring spot
    Peanut stem necrosis
14. **Dwarfing** – a decrease in overall size without alteration of the proportions between the parts of the plant is known as 'dwarfing'
    Eg: rice dwarf virus
    Barley yellow dwarf
    Maize rough dwarf
15. **Rosette**- shortening of internodes with reduction in leaf size is seen. Plants show stunting with bushy appearance.
    Eg: peanut rosette virus
    Rose rosette virus
16. **Swollen shoot:** characterized by mosaic and shedding of leaves, dwarfing and mottling of pods, and especially by shortening and swelling of the internodes of the stem and of the roots
    Eg: cacao swollen shoot virus
17. **Distortion (witches broom)**
    It is a common symptom of virus diseases. This symptom is characterized by the alteration in the symmetry of leaf arrangement, crinkling of edges of the leaf, leaf rolling and leaf resetting, sometimes the leaves become reduced in size, at the internodes and there is production of a cluster of distorted shoots.
    e.g., leaf roll of potato, leaf curl of papaya, leaf curl of tomato etc

Exercise -7

To study about the viral diseases of rice transmitted by insects

Disease	Causal organism	Vector	Virus vector relationship	Symptoms
Rice grassy stunt	Rice grassy stunt virus	Brown plant hopper *Nilaparvata lugens*	**Persistent – propagative manner**	• The infected plants were severely stunted and bore an excessive number of tillers. • The leaves were short, narrow, erect and pale green or yellow in colour. • Young leaves sometimes exhibited interveinal chlorotic mottling or stripes. • Most of the old leaves had numerous characteristic dark brown spots of various dimensions. • The diseased plants generally did not produce any panicles. Sometimes, a few worthless panicles with dark brown grains emerged from the diseased plants. **(Anjaneyulu)**
Rice ragged stunt	Rice ragged stunt virus	Brown plant hopper *Nilaparvata lugens*	**Persistent manner**	• New leaves' development is delayed, and leaves are short, narrower than healthy ones, and darker-green in colour. • They are often deformed, ragged or twisted. Number of ragged or twisted leaves generally decreases as the plant grows and these symptoms may be inconspicuous on new leaves at two months after inoculation. • In some cultivars, infected

				plants are nearly healthy except for slight stunting and occasional appearance of twisted leaves. • Tillering number of infected plants increases at early growth stages but is lower than that of healthy plants at the later tillering stage. • Galls or vein swellings appear along the leaf vein on the outer surface of sheaths and leaf blades at the later tillering stage. • Symptoms become well defined again at heading stage. • The flag leaves of infected plants are often short, ragged and twisted. • Panicle exsertion is delayed and incomplete, and grains are discoloured and unfilled. • Tillers often generate nodal branches which may bear small panicles and retain a green colour after heading. • Symptoms of doubly infected plants include those of ragged stunt, i.e. **ragged or twisted** leaves, and those of grassy stunt, i.e. narrow, short and discoloured leaves and excess tillering. (**Hibino *et al*.,)**
Rice orange leaf disease (ROLD)	*Candidatus Phytoplasma asteris*"	Zig-zag leaf hopper *Recilia dorsalis*	**Persistent**	• Typically, mature rice plants infected with ROLP showed moderate **stunting** and the appearance of a **golden or orange** leaf coloration that initiates at the tip and then progresses downward, followed by an inward rolling of leaves and eventually leading to leaf senescence **(Rivera et al., 1963)**

				• Tiller numbers are slightly too severely reduced, plant height is slightly too severely stunted, and growth habits display erect or spreading phenotypes. • Yield is seriously affected due to the poor growth and reduced tillers of plants. At the seedling stage, it is often lethal when the plant is severely infected.
Rice stripe	Rice stripe virus (RSV)	the small brown plant-hopper (SBPH) *Laodelphax striatellus*	**Persistent and circulative-propagative manner**	• Disease symptoms in rice plants infected by RSV include chlorosis, weakness, necrosis, and stunted growth**. (Satoh *et al.,* 2010**). • In severe infections, leaves develop brown to grey necrotic streaks and die. • Diseased plants produce few or no panicles, and panicles that do form are malformed and discoloured.
Rice yellow dwarf	*Candidatus Phytoplasma oryzae*	Leaf hoppers *Nephotettix virescens*	**Persistent manner**	• Causes general chlorosis of leaves and severely stunted profuse tillers, which are distinct symptoms from ROLD. **(Ling, 1972)** **Other symptoms are:-** • Leaves become soft and droop. • Plants usually remain sterile but sometimes may produce small panicles with unfilled grains. • The chlorotic leaves are uniformly pale green or pale yellow. • Discoloration first appears on the emerging young leaves and then chlorosis on all the succeeding leaves. • Plants infected early may die prematurely. • Those which survive until

				maturity produce only a few defective heads or no heads at all.
Rice tungro disease	Rice tungro spherical and Rice tungro bacilliform virus	Leaf hoppers *Nephotettix virescens*	**Semi-persistent manner**	• Tungro causes stunting of plants, discoloration of leaves and reduction in tiller number. • Tungro-diseased leaves are yellow or orange, slightly rolled outwards, and somewhat spirally twisted. • The leaf discoloration usually starts from the tip of the leaves and may extend to the lower part of the leaf blade. • Young leaves may have a mottled appearance and old leaves shows rusty color specks of various sizes. • The leaf discoloration in tolerant cultivars may gradually disappear at later stages with the formation of new foliage which is dark green in color. • Stunting and leaf discoloration persist throughout the plant growth in susceptible rice cultivars. Infected plants may die, but usually they live until maturity. • The diseased plants of susceptible cultivars may not flower at all, whereas plants of tolerant cultivars may suffer due to abnormal delay in flowering in comparison to healthy ones. • The panicles are often small and not completely exserted. The grains may be sterile sometimes and their quality is greatly affected. **(Anjaneyulu)**
Rice stripe mosaic	Rice stripe mosaic virus (RSMV)	Zig- zag leafhopper *Recilia dorsalis*	**Persistent – propagative manner**	• Rice is susceptible to RSMV during all growth stages, but the symptoms depend on the

				growth stage at the time of infection. • Plants infected before the three-leaf stage show dwarfing, yellow stripes, mosaicking, inward-curling leaves, excessive tillering, and failing to head. • Plants infected at the early tillering stage show slight symptoms, resulting in dwarfing, leaves with partial stripes and mosaics, slightly increased tiller numbers, and unfilled grains. • Plants infected at the late tillering stage show no visible symptoms and can head normally. • In addition, plants infected in warmer environments show obvious striped mosaic symptoms and their leaves may be severely deformed and curled. • Severely affected fields typically show obvious disease centers; diseased plants appear alternately with healthy plants and are distributed mainly near or at field edges **(Chen *et al*.,2019)**
Rice hoja blanca disease	Rice hoja blanca virus(RHBV)	Rice delphacid *Tagosodes orizicolus*	**Circulative, Propagative**	• This disease could induce in susceptible rice cultivars, as a result of seedling death, reduced photosynthetic capacity plant dwarfing and panicle sterility. • Affected rice plants showed the characteristic yellowish, chlorotic stripes that often coalesce to give RHB its name **(white leaf)**: stunting, panicle sterility and/or plant death.

				• Affected plants may show the disease symptoms in some tillers, while other tillers remain symptomless. • The panicles of diseased tillers are shorter and malformed, including the lemma and palea of florets that dry out and show a brownish discoloration**. (Galvez ,1969)**
Rice Yellow Mottle disease	Rice Yellow Mottle Virus (RYMV)	Chrysomelid beetles *Dicladispa viridicyanae* *Sesselia pusilla,* *Chaetocnema pulla, and* *C. dicladispa,*	**Semi persistent manner**	• Symptoms of RYMV on *O. sativa* are chlorotic dotting's of leaf bases, elongating parallel to veins to produce mottling and stunting. • The disease which is characterized by mottle and yellowing symptoms of varying intensities depending on genotype and this could be mistaken with iron and nitrogen deficiency **(Onasanya *et al*., 2006).** • RYMV infected rice plants usually develop pale yellow mottle leaves, stunted, and reduced tillering, non-synchronous flowering, poor panicle exertion and spikelet discolouration. **Gnanamanickam (2009**)



Rice grassy stunt virus disease



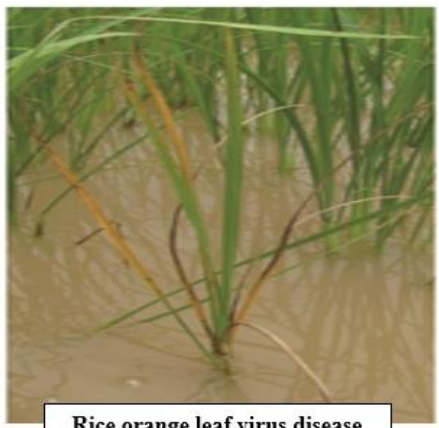
Rice tungro virus disease



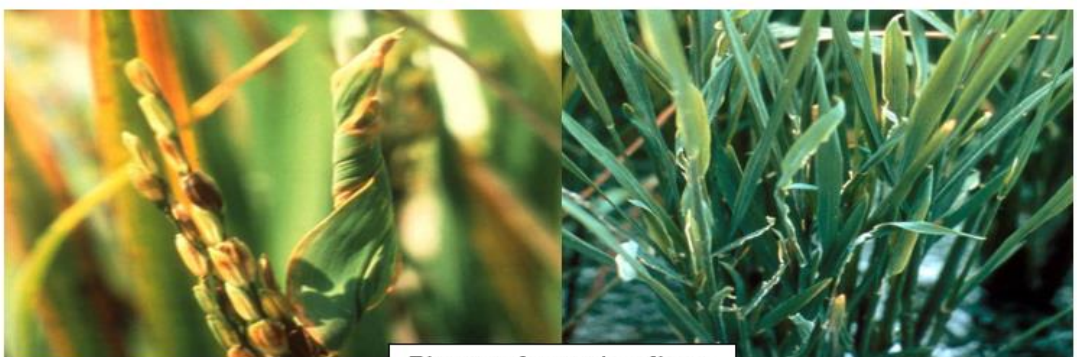
Rice hoja blanca disease



Rice stripe virus disease



Rice orange leaf virus disease



Rice ragged stunt virus disease

Exercise -8

To study about the viral diseases of Maize, Wheat and Barley transmitted by insects.

Disease	Causal organism	Vector	Virus vector relationship	Symptoms
Maize mosaic disease	Maize mosaic virus	Corn plant hopper *Peregrinus maidis* Delphacidae	**Persistent manner**	• Appearance of fine, discontinuous, chlorotic streaks between the leaf veins and stunting of the plant characterize MMV infection. • The lesions become necrotic as the disease progresses. • Early infected plant dies sooner or later without emergence of ear head. • Plants infected at later stages may develop ear head with or without grain. • In case of infection of multiple viruses, the symptoms may vary and that may create confusion at field level identification. **(IIMR)**
Maize streak disease	Maize streak virus(MSV)	Leaf hoppers *Cicadulina mbila* and *Cicadulina storeyi*	**Persistent manner**	• Streak disease initially manifests as minute, pale, circular spots on the lowest exposed portion of the youngest leaves. • The only leaves that develop symptoms are those formed after infection, with older leaves remaining healthy. • As the disease progresses, newer leaves emerge containing streaks up to several millimetres in length along the leaf veins, with primary veins being less affected than secondary or tertiary veins.

				• The streaks are often fused laterally, appearing as narrow, broken, chlorotic stripes, which may extend over the entire length of severely affected leaves. • Lesion colour generally varies from white to yellow, with some virus strains causing red pigmentation on maize leaves and abnormal shoot and flower bunching in grasses. • Reduced photosynthesis and increased respiration usually lead to a reduction in leaf length and plant height; thus, maize plants infected at an early stage become severely **stunted, producing undersized, misshapen cobs or giving no yield at all**. Yield loss in susceptible maize is directly related to the time of infection: • Infected seedlings produce no yield or are killed, whereas plants infected at later times are proportionately less affected. **(Shepherd *et al*., 2009)**
Maize rough dwarf disease	Maize rough dwarf virus (MRDV)	Plant hopper *Laodelphax striatellus*	**Persistent-propagative manner**	• The diagnostic symptom of maize rough dwarf is small (< 2 mm) irregular growths, or enations, on the underside of leaves that make the leaves rough to the touch. • Infected plants also tend to be dark green in colour, have shortened internodes leading to dwarfing, and poorly developed root systems. • Yield losses can be significant **(Li Li, and Yuan, 1999)** • Longitudinal splits of roots occur, particularly in adventitious roots. • Plants are dwarfed though the stem remains stout. • Leaf Necrosis

				• Reduced Ear Size • Delay in Tasseling and Silking
Corn stunt disease	*Spiroplasma kunkelii*	Corn leaf hopper *Dalbulus maidis*	**Persistent - propagative manner**	• Symptoms of Corn Stunt disease appear three to five weeks after inoculation of *S. kunkelii* and become more severe with time and to the newest parts of the plants as they develop. • Mild symptoms include typically leaves with **chlorotic stripes** that appear near the base and extend towards the leaf tips. **(Nault, 1980)** • Alternatively, leaves may show **reddening or deformations cuts in the margins**. • Severe symptoms appear as **shortened internodes**, which gives its name to stunting, and in some cases **ear proliferation** or even lack of reproductive structures of the plant. • Reduced yield resulting from Corn Stunt disease is directly related to symptom severity and the accumulation of the pathogen S. *kunkelii* which are both highest if *S. kunkelii* is inoculated at early growth stages. In this situation, reduced yield may be high, ranging from 12 to 100%. **(Massola junior *et al*.,1999)** **Pic credit: Lowell R Nault**
Maize bushy stunt	*Maize bushy stunt Phytoplasma (MBSP)*	Corn leaf hopper *Dalbulus maidis* *D. elimatus* and *Graminella nigrifrons*	**Persistent manner**	• MBSM causes more severe stunting and proliferation of axillary and basal shoots than does MSS. At high temps. • MSS (but not MBSM) causes chlorotic spots and stripes on leaves. • At low temperatures, chlorotic spots and stripes may not develop **(Nault, 1980)**

Stewart disease in corn	**Bacteria** ***Pantoea stewartii***	Corn flea beetle *Chaetocnema pulicaria*	**Persistent manner**	• Stewart's wilt appears as two different phases on corn. The first phase is a seedling wilt, which occurs when young plants are infected systemically. Once the tassels emerge, the leaf blight phase may occur. **Seedling wilt** • Rapid wilting occurs in highly susceptible varieties. • Linear lesions with wavy margins develop parallel to leaf veins. • These lesions form at the site of insect feeding wounds. • Lesions may be pale green to yellow in colour and turn tan-brown as leaves die. • Discoloration and cavities in the pith near the soil line may be present in severely infected plants. **Leaf blight** • Foliar symptoms are similar to the seedling wilt phase and are generally most apparent after tasseling. • Lesions form at the site of insect feeding wounds. • Entire leaves may die and dry up. • Bleached, dead tassels form on plants that survive seedling wilt. • This phase is not as damaging as the seedling wilt phase. (**Bradley *et al*.,)**
Maize stripe	Maize stripe virus (MStV)	Plant hopper *Peregrinus maidis*	**Persistent manner**	• Characteristic symptoms on sorghum are appearance of continuous chlorotic stripes/ bands between the veins of the infected leaf, which become yellow with continuous stripes progressing from the base towards the tip of the leaves. • Affected plants appear stunted

				and height depends on stages of infection. • Infected plant often fails to exert ear head (arrow). • The disease is also known as chlorotic stripe stunt or sorghum stripe disease (SStD). **(IIMR)**
Wheat streak mosaic	Wheat streak mosaic virus (WSMV)	Wheat curl mite/ Eriophyid mite *Aceria tosichella*	**Persistent manner**	• Typically, infected plants are stunted, degree of stunting depends on how early infection took place, may be splayed on the ground, and do not tiller as well as unaffected plants. • Foliar symptoms include a light green to yellow mottled mosaic; more advanced infections may develop yellow streaks running parallel to the veins. • Tightly rolled and trapped leaves may also be evident and are the result of feeding damage that occurs when large numbers of wheat curl mites are present. **(Wheat and small grains, Washington state university)**
Wheat Yellow mosaic/ Wheat spindle streak mosaic	Wheat yellow mosaic virus (WYMV)	Obligate parasitic fungal pathogen *Polymyxa graminis,*	**Persistent manner**	• At crop "green-up" (typically, mid- to late March) random yellow to light green dashes running parallel to the leaf veins occur on foliage. • With age, some dashes will be pointed at one or both ends and may have an island of green tissue in their center. • These classic "spindle"-shaped lesions give the disease its name. • Diseased plants are slow to Greenup in early spring compared to healthy fields. • When symptoms persist, affected plants may be stunted and thin. **(Hershman, 2011)**

Barley yellow dwarf	Barley yellow dwarf virus (BYDV)	**Aphids** *Rhopalosiphum maidis* *R.padi* *Sitobion avenae*	**Persistent - circulative**	• Reddening of the leaves and blasting of the florets are easily observed. **(Oswal and Houston, 1953)** • Other symptoms are stunted growth and late heading **(Yount *et al*., 1985)** • Chlorosis • Plant physiological processes are interfered by virus that multiplies specifically within the phloem of the host plant. • The infected phloem cells are destroyed and translocation of assimilates produced by leaves is reduced. • This result in carbohydrate accumulation, which in turn increases dry weight, inhibits photosynthesis and reduces chlorosis content that subsequently cause discoloration and thickening of leaves**. (Jensen, 1968)**
Ragi mosaic	Ragi mosaic virus (RMV)	Leaf hopper *Cicadulina bipunctella* *Rhopalosiphum maidis*	**Persistent manner**	• The first symptom is **chlorosis**, followed by **mosaic mottling** and severe stunting of the plant. • The entire plant becomes pale, dwarfed and sterile. • Rarely the affected plants come to ear and if formed the panicle is mostly chaffy. • Closer examination of the plant may reveal such symptoms as characteristic dark brown lesions on the basal stem as found in *Helminthosporium* rots, secondary root formation from the nodes much above ground level, and fungal masses in the split open culm. • As the disease advances, the plants wither prematurely and the diseased crop is easily identified

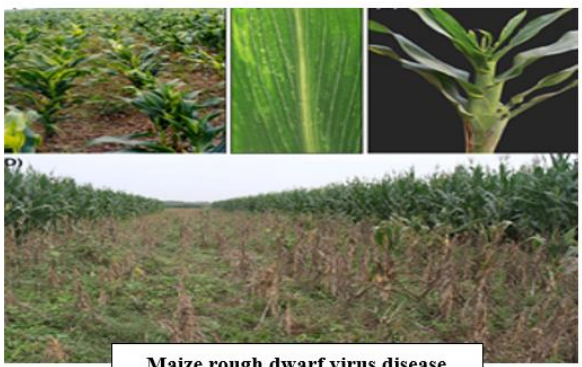
				from a distance.
Ragi streak	Maize streak virus-A strain	Leaf hopper, *Cicadulina chinai* and *Cicadulina bipunctella*	**Persistent manner**	• Symptoms appear on young leaves as pale specks or stripes, which coalesce forming chlorotic bands running parallel to midrib. • Bands may be interrupted by dark green areas. Infected plants produce tillers and bear yellowish ears bearing few shrivelled seeds **(IIMR)**



Maize mosaic virus disease



Maize streak virus disease



Maize rough dwarf virus disease



Corn stunt virus disease





Rice ragged stunt virus disease



Maize stripe virus disease



Wheat streak mosaic virus disease



Barley yellow dwarf virus disease

Exercise -9

To study about the viral diseases of Pulses transmitted by insects.

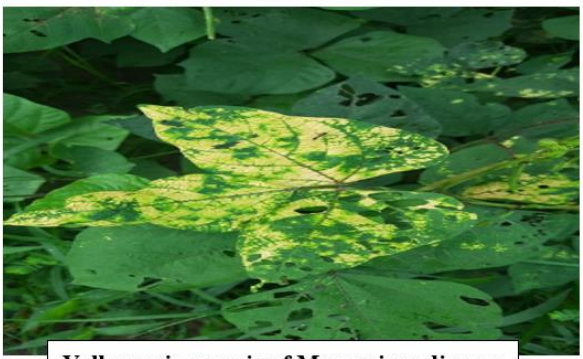
Disease	Causal organism	Vector	Virus vector relationship	Symptoms
Yellow vein mosaic of Mung	Mungbean yellow mosaic virus (MYMV)	White fly *Bemisia tabaci*	**Circulative, and persistent manner**	• The visible symptoms appear as scattered yellow-colour spots on the young leaves which later turns into a yellow mosaic pattern and ultimately results in complete yellowing, drying and withering of leaves. • The pods on the infected mungbean plant become smaller in size, yellowing of the leaves decreases the photosynthetic efficiency which ultimately manifested as severe yield penalty (**Malathi and John, 2009**).
Yellow vein mosaic of Urd	Urd yellow vein mosaic virus	White fly *Bemisia tabaci*	**Circulative, and persistent manner**	• Yellowing of the entire network of veins in the leaf blade is the characteristic symptom. • In severe infections the younger leaves turn yellow, become reduced in size and the plant is highly stunted. • The veins of the leaves will be cleared by the virus and interveinal area becomes completely yellow or white. • In a field, most of the plants may be diseased and the infection may start at any stage of plant growth. • Infection restricts flowering and fruits, if formed, may be smaller and harder. • The affected plants produce fruits with yellow or white colour and they are not fit for marketing. • In urdbean two types of symptoms viz., **yellow mottle and necrotic mottle**

				were considered to be caused by different genotypes of the same virus isolates.
Mungbean Leaf Curl	Mungbean leaf curl virus (MLCV)	Thrips *Frankliniella schultzei*	**Persistent manner**	• Reported that infected mungbean leaves shows downward curling, venial necrosis, chlorotic area developed on leaf lamina and over all stunting of the plants and finally death of affected plants due to apical necrosis has been observed. • Even late infection reduced number of pods which either produced smaller or larger seeds or no seeds at all. • The virus also produces characteristic ring spots on cowpea and necrotic lesion on Petunia**. (Ghanekar *et al.,* 1979)**
Mung bean phyllody	*Candidatus Phytoplasma trifolii*	The brown leaf hopper *Orosius orientalis*	**Persistent manner**	• Infection includes leaf yellowing, small leaf size, virescence, developmental aberrations (proliferation, dwarfism). • Showed severe symptoms of phyllody and a bushy appearance. • Stem, leaf and stalk phloem sections from plants with and without symptoms were examined under a light microscope (CXRII, Labomed, CA, USA) using Dienes' stain. • Transformation of floral parts into green, leaf-like structures **(Akhter *et al.,* 2010).**
Soybean mosaic disease	Soybean mosaic virus (SMV)	Aphid *Aphis glycines*	**Non-persistent manner**	• The appearance of yellow vein clearing on new trifoliate leaves is the first symptom of SMD. • The downward curving of the leaf margin at the sides and upward curving of the leaf tip also occur in the infected plant of soybean. **(Brand *et al.,* 1993)** • The leaves give course and leather appearance and become brittle before their maturity stage. • The growth is stunted and less number of poles are reduced infected plant

				compared to the healthy plant. • Mottling also occurs during cold weather conditions and the plant becomes masked during warm conditions. • The localized lesions are also produced on the leaves. **(Hajimorad *et al*., 2005)**
Bean common mosaic	Bean common mosaic Virus (BCMV)	Aphid *Myzus persicae* and *Aphis fabae*	**Non-persistent manner**	• The disease first appears in the form of irregular light green patches alternating with normal green areas. • The size of leaf gets reduced and the margins show upward rolling. • Later on, these young leaves show puckering and blistering and the normal green areas are seen on both sides of the longer veins, and the leaves become rough and brittle. • Affected plants are stunted and often display excessive branching **(Talens and Talens, 1978).** • In severe infection, complete inflorescence in changed into a leafy structure resulting in complete seed loss**.(Walter and Mossahebi,1974)**
Cowpea mosaic disease	Cowpea mosaic virus(CPMV)	Aphid *Aphis craccivora* *Aphis gossypii* *Myzus persicae*	**Non-persistent manner**	• First systemic symptoms appear about 10 days after infection and consist of a dark vein banding. • These viruses produce a mosaic pattern (intermixing of green and yellow patches) on leaves. • They cause irregular light and dark green mosaic patterns on the leaves. • Some viruses cause thickened, malformed and distorted leaves. • The mosaic patterns are best observed on the younger foliage. • Plants may be stunted and fail to produce normal pods. • If the disease attacks plants at the early growth stage, no pods should be expected. • Mixed infection with more than one virus is frequent in cowpea.

				• Infection with multiple viruses results in much more severe symptoms and dramatic reduction in yield.
Cowpea leaf curl	Mungbean yellow mosaic india virus (MYMIV)	Whitefly *Bemisia tabaci*	**Persistent and circulative manner**	• Affected plants showed a yellow mosaic with downward leaf curling, vein swelling and vein enations. • A few leaves showed only mild leaf curl symptoms, while others showed a yellow mosaic without enation. • The majority of the leaves showed a yellow mosaic with severe leaf curl and enations**. (Rouhibakhsh and Malathi, 2005)**
Cowpea witches broom	Phytoplasma	Leafhoppers, plant hoppers, and psyllids.	**persistent, propagative manner**	• The diseased plants produced excessive branches (broom like) and the size of the leaves is considerably reduced. • Including reduced leaf size, chlorosis, and also found a large number of leafhoppers near the diseased plants. • At later stages, the affected plants trial on the ground. **(wang *et al.*, 2023)**
Curly shoot on French bean	Tobacco curly shoot virus (TbCSV)	White fly *Bemisia tabaci*	**Circulative and persistent manner**	• Infected plants of common bean exhibit Stunting, Stem twisting, Curly shoot, Thickening of lower surface veins and Galling with dark green colour.
Pea enation mosaic	Pea enation mosaic virus (PEMV)	Pea Aphid *Acyrthosiphon pisum*	**Circulative, Non propagative**	• In peas, PEMV causes downward curling of the leaves, chlorotic and translucent spots on the leaves, and vein clearing. • As the disease progresses, malformations, epinasty, severe stunting, and rugosity may be observed on the leaves. • Enations (hyperplastic outgrowths) are associated with the veins, develop underneath the leaf lamina and hence the name, pea enation. • The pods are distorted, covered with warts, and bear few peas**. (Makkouk and Kumara, 2012)**
Redgram sterility	Pigeon pea	Eriophyid Mite	**semi-persistent**	• The affected plants are stunted due to shortening of internodes.

mosaic / Pigeon pea sterility mosaic /Green plague of Piegon pea	sterility mosaic virus (PPSMV)	*Aceria cajani*	**manner**	• Some plants exhibit clear mosaic and ring spot symptoms. • The leaf size, flowers and pods are reduced. • The severely infected plants do not produce flowers and pods, if formed they are sterile. • Severe mosaic in leaflets with complete sterility. • Mild mosaic with partial sterility. • Ring spot symptoms are characterized by Green Island surrounding by a chlorotic halo on leaflets and this symptom disappear as the plant mature (no sterility). • This disease sometime referred as "**GREEN PLAGUE**" because at flowering time affected plants are green with excessive vegetative growth and having no flowers or seedpods. (**Jones *et al.*, 2004**).
Pigeon pea yellow mosaic	mungbean yellow mosaic virus (MYMV)	The whitefly *Bemisia tabaci*	**Circulative manner**	• The disease symptoms include yellow diffused spots interspersed with green islands on leaves and often the entire lamina becomes yellow **(Nene, 1972).** • Symptoms of PYMD are characterized as yellow mosaic, mottling, shortening of leaves and stunting.
Gram phyllody/chickpea phyllody	*Candidatus phytoplasma*	The leafhopper *Orosius orientalis and Hishimonus phycitis*	**Persistent, propagative manner**	• The major symptoms were floral virescence, phyllody and extensive proliferation of the branches. **(Akhtar *et al*., 2009)** • In early stage of infection, pods are not produced after the onset of infection. • In later stages of infection, phyllody can be less pronounced and small sickle shaped pods and shrivelled seed may also form. • Infected plants are commonly stunted and bushy in appearance and remain green after surrounding plants have matured. • Yellowing, floral sterility also appears.



Yellow vein mosaic of Mung virus disease



Yellow vein mosaic of Urd virus



Mungbean leaf curl virus disease



Mungbean phyllody disease



Soybean mosaic virus disease



Cowpea mosaic virus disease



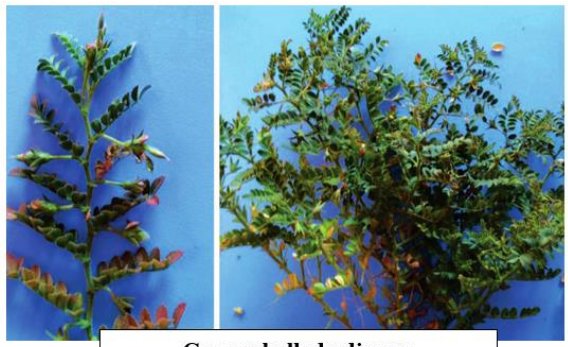
Cowpea leaf curl virus disease



Cowpea witches broom disease



Red gram sterility mosaic virus disease



Gram phyllody disease

Exercise -10

To study about the viral diseases of vegetables transmitted by insects.

Disease	Causal organism	Vector	Virus vector relationship	Symptoms
Little leaf of Brinjal	*Phytoplasma trifolii*	Brown Leaf hopper *Hishimonus phycitis, Amrasca biguttula biguttula and Empoasca devastans*	**Persistent manner**	• The leaves of the infected plants in the early stages are light yellow in colour. • The leaves show a reduction in size and are malformed. • Disease affected plant are generally shorter in stature bearing a large number of branches, roots and leaves than healthy plants. • The petioles get shorter considerably, many buds appear in the axil of leaves and internodes get shortened thus giving the plants a bushy appearance. • Flower parts are deformed leading the plants to be sterile. • Infected plants do not bear any fruit. However, if any fruit is formed it becomes hard and tough and fails to mature. **(National Horticulture Board)**

Brinjal leaf curl	Tomato leaf curl Joydebpur virus	White fly *Bemisia tabaci*	**Persistent circulative manner**	• Infected plants exhibiting symptoms, predominantly of **leaf curl, little leaf and mosaic**. • The incidence of leaf curl disease varied between fields at different locations and ranged between 10% and 20%. **(IIVR)**
Brinjal mosaic	Potato Virus Y	Aphids (*Aphis gossypii* and *Myzus persicae*).	**Non-persistent manner.**	• The important symptoms of the disease are mosaic mottling of the leaves and stunting of plants. • The leaves of infected plants are deformed, small and leathery. • Plants show a stunted growth when infected in the early stages. **(NHB)**
Yellow vein mosaic of Okra	Bhendi yellow vein mosaic virus (BYVMV)	White fly *Bemisia tabaci*	**Persistent Circulative manner**	• When okra plants are infected with bhendi yellow vein mosaic viruses under filed conditions, they will induce three types of visual symptoms on okra plants. • **In first type**, the leaves of the young plants infected very early in the season become complete yellow and later turn brown and dry up. • **In the second type**, plant infection started after flowering. upper leaves and flowering parts show vein clearing symptoms.

				Infected plants produce some fruits but they became yellow and hard at picking stage. • **In third type**, plants continued to grow in a healthy state and fruiting is normal till late in the season but, at the end, few small young shoots appear at the basal portion of the stem, which showed vein clearing. • However, in such plants yield was as good as symptom less plants (**Venkataravanappa *et al.* 2012**).
Okra enation leaf curl disease	Okra enation leaf curl virus (OELCuV)	White fly *Bemisia tabaci*	**Circulative persistent manner**	• The disease initially causes small pin-head enations on the under surface of leaves. • This is followed by a warty and rough texture of leaves, with later leaves curling upwards. • Affected plants show a twisting of the stem and lateral branches with leaves becoming thick and leathery. • The curling and enations are more prevalent on leaves that develop soon after infection than in later leaves and plants are severely stunted with fruit being small, deformed and unfit for marketing (**Singh,1996)**

Tomato leaf curl	Tomato leaf curl virus	White fly *Bemisia tabaci*	**Persistent manner**	• Infected tomato plants show characteristic upward cupping, distortion and interveinal yellowing of leaves, severe stunting, degeneration, and flower abortion. • These symptoms often lead to substantial yield losses, especially if the plants are infected at an early growth stage.(**Antignus and Cohen, 1994)**
Tomato spotted wilt	Tomato spotted wilt virus (TSWV)	Thrips *Frankliniella occidentalis*	***Persistent and circulative-propagative manner***	• In tomato leaves, the virus causes characteristic bronzing or purpling, downward curling; leaf distortion; brown, reddish, bronze-colour, or yellowish concentric rings; irregular whitish or necrotic leaf spots and flecking; complete plant stunting and yellowing (**Anon. 1991).** • Tomato fruit formed prior to infection appear normal whereas fruit that develop later may have pronounced symptoms. • Green tomato fruit often develop pale green, white or yellowish blotches and spots (often with concentric zones of different colours), or

				small bumps on the surface. • Severely affected plants may not form fruit or the fruit may be very small and unmarketable (**Pataky, 1991)**
Tomato ring spot	Tomato ring spot virus(ToRSV)	Nematode *Xiphinema americanum* and chrysomelid beetles	***Semi persistent manner***	• Ring spots or yellow rings blotch patterns on the foliage. • Decline in plant growth and a reduction in fruit set. • Shortened internodes. • Stunting and small clusters with tiny fruits. • Infected leaves are cupped and malformed with circular spots 2 to 5 mm in diameter. • Necrotic spots can also occur on canes. Young leaves may be strap like and mottled. • Symptoms are variable within the same plant. Infected plants may be defoliated by mid-harvest and eventually die, often after a severe winter. The disease spreads slowly in the field. Roughly oval-shaped patches of weak or dying plants develop over several years.
Tomato big bud disease	Phytoplasma	The beet leafhopper (BLH) (*Neoaliturus tenellus*)	**Persistent manner**	• Symptom of big bud disease is the unique swollen-looking

				flower bud. The green sepals become enlarged and may not open, and if they do, the flower inside shows abnormal development. • Symptomatic flower buds will not produce fruit. • Diseased plants sometimes have a bushy appearance. • This is due to a shortening and thickening of the stems between the internodes which sprout numerous stunted and distorted leaves. • The stems develop an upright growth habit and the whole plant takes on a pale or yellow cast. **(Nischwitz, 2022)**
Tomato mosaic	Tomato mosaic virus (ToMV)	**Transmitted by Mechanical friction**	--	• Symptoms can be found during any growth stage and all plant parts are affected. • Generally, infected plants have a light or dark green mottling or mosaic with distortion of younger leaves, and stunting to varying degrees. • Severely affected leaves may have a "fernlike" appearance and may show raised dark green areas. • Fruit set may be

				severely reduced in affected plants. • There may be internal browning of the fruit wall, yellow blotches and necrotic spots may occur on green or ripe fruit. • Some strains can cause yellow mottling of leaves; others cause dark necrotic streaks in stems, petioles, leaves or fruit, or other symptoms to occur. **(Fact sheet, TMV,AVRDC)**
Tomato mottle mosaic	Tomato mottle mosaic virus (ToMMV)	Whiteflies *Bemisia tabaci*	**Persistent manner**	• ToMMV-SD caused symptoms such as severe mosaic, mottling, and necrosis of tomato leaves, yellow spot and necrotic lesions on tomato fruits. • Causes significant loss in yield and quality of tomato fruits. • leaf and shoot chlorosis, uneven ripening, as well as leaf distortion also appears
Tomato necrotic ring spot	Tomato necrotic ring spot virus (ToNRV)	Thrips *Thrips palmi* and *Ceratothripoides claratris.*	**persistent propagative manner**	• Infected plants showed symptoms consisting necrotic spots, necrotic ring spots, stem necrosis, Leaf necrosis. **(Seepiban *et al*., 2011)**
Cucumber mosaic on tomato	Cucumber mosaic virus (CMV)	Aphids	**Non-persistent manner**	• CMV is one of the important viral pathogen of tomato

				where it induces various symptoms viz., necrosis, mottling, mosaic, narrowing or shoe-string of leaves and stunting of plants. • Various symptoms like yellowing, mottling, twisting, shoe-string of leaves, leaf distortion and fern-like appearance of the leaves on tomato infected with CMV. **(IIVR, Varanasi)** **Indian institute of vegetable research**
Onion purple blotch	*Alternaria porri*	Thrips *Thrips tabaci* **Fact sheet by H. F. Schwartz**	**Propagative, Persistent**	• The symptoms occur on leaves and flower stalks as small, sunken, whitish flecks with purple coloured Centre's. • The lesions may girdle leaves/stalk and cause their drooping. • The infected plants fail to develop bulbs. • The intensity of disease varies from season to season **(NHB, Bangalore)**
Iris yellow spot of onion and garlic	Iris yellow spot virus(IYSV)	Thrips *T. tabaci*	**Persistent manner**	• Symptoms include yellow to straw colored lesions on leaves and scapes, and dry, elongated lesions or flecks that may resemble severe thrips feeding injury. • Lesions may be

				diamond-shaped, but this occurs more commonly on scrapes than on leaves. • Leaves shows curling and twisting and have white or silvery blisters Entire plant looks blemished and turns white. • Severe disease on leaves may reduce bulb size. • Lesions on seed stalks may cause lodging (plant toppling) during seed set, when the weight of the umbel increases. • Straw-coloured, spindle shaped spots with poorly defined end leaves. • These spots coalesce to form larger patches on leave. • Clearly visible on the older leaves. **(Karuppaiah *et al*.,2018)**
Onion yellow dwarf	onion yellow dwarf virus	The green peach aphid *Myzus persicae*	**Non persistent manner**	• Four different types of symptom were observed which have been designated as grades A-D. • **Grade A**-bushy type plants with more flattened, narrow and pale to yellow coloured leaves. • **Grade B**-crinkling, development of prominent yellow coloured stripes and

				lop over with tips touching the ground due to loss of turgidity in the leaves, yellow coloured stripes on scapes with twisting and bending. • **Grade C**-faint chlorotic stripes on leaves and slight curling and twisting of scapes and • **Grade D**-chlorotic streaks produced on the leaves and scapes (**Kumar *et al*., 2012)**
Chilli leaf curl	Chilli leaf curl virus(ChiLCV)	White fly *Bemisia tabaci*	**Persistent - Circulative- and Non - propagative manner**	• The symptoms of ChiLCV infection include upward curling in the leaves, crinkling appearance, puckering, leaf area reduction, blistering at interveinal areas. • Vein banding, shortening of petioles, and internodes, bunchy leaves, and severe stunting in plants. **(Kumar *et al*., 2014)** • If the disease persists till the late growth stages of the plants, flower buds show abscission and sterile anthers may set without or abnormal pollen grains, which ultimately produces poor fruit and low fruit setting, distorted or underdeveloped fruits **(Kumar *et al*., 2015)**

Upward curling of Chilli leaves	--	Thrips *Scirtothrips dorsalis*	**Propagative, Persistent**	• Discoloration of buds. • Boat shaped curling of leaves. • Buds become brittle and drop down. • Softening of fruits and deformation of fruits. • Leaf size reduction and linear thickenings of the leaf lamina. • Silvering of leaf surface. • Grey to black markings on fruits often forming a conspicuous ring around the apex. • The infested leaves develop crinkles and curl upwards.
Downward curling of chilli	--	Chilli mite/ Broad mite/ yellow mite/Murunai mite *Polyphagotarsonemus latus*	**Semi-persistent**	• **Inverted boat shaped leaves which leads to murunai disease** • Downward curling and crinkling of leaves • Leaves with elongated petiole • Stunted growth
Chilli mosaic	Chilli mosaic virus (ChiMV)	Aphids *Aphis gossypii* and *Myzus persicae*	**Persistent or non-persistent manner**	• Infected fruit appears mottled and develops raised "warty" areas. • Mottling of leaves, Yellow, white or green stripes/ streaks/ spots on foliage. • Dark green vein-banding are the most characteristic symptoms. • Additionally, infected plants become stunted

				and produce smaller and distorted leaves and have dark-green streaks on their stems and branches. • Also flowers drop are common and such plants produce mottled and distorted fruit. • Dark green blisters **(IIVR)**
Potato leaf roll	Potato leaf roll virus(PLRV)	Aphid *Myzus persicae*	**Persistent and circulative manner**	• Plants affected with leaf roll have an upward rolling of the leaflets on the midrib giving them a tubular form and the plant a stiff, erect appearance. • The lower leaves are always rolled and leathery or brittle, often dying from the tips backward in advanced stages. • Other leaves may roll also. The leaves are generally somewhat chlorotic and the plants are considerably dwarfed. • When the plants are affected by current-season infection the leaf rolling and loss of color show up first in the topmost (younger) leaves. • Some of the tubers infected with leaf roll show net necrosis, but this is not a constant symptom. **(Mc Kay and Dykstra)**

Potato virus Y	Potato virus Y(PVY)	Aphids *Myzus persicae*	**Non-persistent manner**	• Symptoms caused by PVY infection can vary depending upon the strain and potato variety grown. • A rugose mosaic symptom is characteristic for some strains, but is most commonly ascribed to a mixture of PVY and PVX. • Other strains produce a general mosaic or a hypersensitive (severe necrotic) reaction. • Necrosis may progress to total leaf collapse, with the dead leaflet clinging to the stem.
Potato crinkle	Potato virus A	Aphid *Myzus persicae*	**Non-persistent manner**	• It is characterized by a prominent mottling and crinkling of the leaflets. • The mottled spots are large and have a tendency to be noticeable especially around the margin of the leaflets. • The symptoms are partly or completely masked by high temperature. • It differs from mild mosaic in that the leaflets are more ruffled and the blotches are larger. • It can be distinguished from rugose mosaic by the larger blotches and by the absence of

				necrosis on the veins of the lower leaves. **(Mc Kay and Dykstra)**
Witches broom of potato	*Phytoplasma trifolii*	Brown Leaf hopper *Hishimonus phycitics*	**Persistent manner**	• Plants affected with this disease are characterized by numerous spindling Stems and small leaves velvety in appearance. • The tubers produce numerous slender, spindling sprouts. • Some of the affected tubers show net necrosis. • Affected plants yield a large number of tubers, but none or only a few are of marketable size. • The majority of the tubers may be about the size of a marble. **(Mc Kay and Dykstra)**
Rugose mosaic of potato	Potato virus X and Potato virus Y	Aphid *Myzus persicae*	**Non-persistent manner**	• The mottled areas are smaller, more numerous, and grouped closer to the main veins. • During high temperature the mottling may be completely masked, but the crinkling of the leaves and their tendency to curl slightly downwards and make the identification of this disease certain. • Some of the veins of

				the lower leaves generally are necrotic, resembling black, pencil-like lines. • The affected plants are noticeably stunted and generally die prematurely. • Characterized by a burning or necrosis of the veins of the newly developed leaves and a dying of the tissue between the veins. • These leaves will eventually drop, or hang on by a thread of tissue of the stem. **(Mc Kay and Dykstra, 1938)**
Potato scab	Soil bacteria *Streptomyces scabies*	*Potato flea beetle Epitrix cucumeris*	semi-persistent and persistent	• Potato scab lesions on tubers can be quite variable but generally appear as rough, corky lesions, which may range from small and rose to deeply pit. • Initially, infections appear as small tan to reddish-brown spots on the tuber surface. • Pitted scab can be as deep as one half inch into the tuber. • Tubers with russetted scab can have large areas superficially covered with corky tissue. • Infections can also occur on the stems, stolons, or roots. • Russetted varieties tend to be less

				affected than smooth-skinned varieties. • Susceptibility varies considerably, but even the most resistant varieties may have significant amounts of disease in some years.
Potato purple top	Phytoplasma	Leaf hopper *Scleroracus flavopictus*	**Persistent manner**	• Apical leaves are pinched or curled, roll inward and develop yellowish purple pigments. • Infected plants lose their apical dominance and proliferation of axillary buds, shortened internodes and swollen nodes and aerial tubers occurs. • Plants may wilt and die prematurely. These plants commonly form hair sprouts. • Primary symptom is purple-top wilt, and the haywire stage is due to secondary infection **(Conner's , 1967)**
Cucumber mosaic disease in cucurbits	Cucumber mosaic virus	Aphid *Myzus persicae*	**Non-persistent manner**	• Symptoms seen with this virus include leaf mosaic or mottling, yellowing, ringspots, stunting, and leaf,**(vegetable MD online)** • Flower and fruit distortion. CMV also induces a type of symptom on leaves known as the **"shoestring"** effect

				on many host species. • This effect causes young leaves to appear narrow and the entire plant to be stunted**.(CMV, AVRDC,2006)** • CMV can cause cucumbers to turn pale and bumpy. The leaves of these plants turn mosaic and their rugosity is often changed, making leaves wrinkled and misshapen. • Growth of these plants is usually also stunted and produces few flowers. • Often, cucumber fruits are oddly shaped, appear gray, and tasted bitter. These appearances lead to them being referred to as "white pickles".
Cauliflower mosaic	Cauliflower mosaic virus(CaMV)	Aphids *Brevicoryne brassicae Myzus persicae*	**Semi persistent manner**	• In addition to the typical symptoms of vein-clearing, vein-banding, leaf distortion and "enations", three other symptoms of the virus occurred in cauliflower. • When plants were grown at a low light intensity, discrete chlorotic local lesions sometimes appeared on inoculated leaves. • Systemically infected leaves occasionally bore chlorotic spots

				instead of, or in conjunction with, vein-clearing or vein-banding. • Many varieties of cauliflower also developed dark necrotic areas and spots, varying from minute specks to areas 3 mm. in diameter, and resembling the symptoms described by **van Hoof (1952)** in cabbage. • The banding along the veins was always dark green at first, with lighter inter-veinal areas, but leaves developed later sometimes had light banding along the veins with darker areas between. • The vein-banding on some younger leaves of all the indoor plants faded in late May and June, when the mean temperature over a period of twenty days averaged 25° C. • The interveinal areas became dark green, but had lost the waxy "bloom"; this was retained by the bands along the veins, which became dark metallic blue. **(Broadbent and Tinsley, 1953)**
Bacterial wilt of Cucurbits	*Erwinia tracheiphila*	Striped and spotted cucumber beetle *Acalymma vittatum*	**Semi-persistent manner**	• Initially, individual leaves or groups of leaves turn dull green

		and *Diabrotica undecimpunctata*		and wilt, followed by wilting of entire runners or whole plants. • At first, plants may partially recover at night, but as disease progresses, wilt becomes permanent. • Collapsed foliage and vines turn brown (necrotic), shrivel, and die. • Wilt symptoms may be noticeable in as few as 4 days from infection on highly susceptible hosts but can take up to several weeks to become evident on crops that are less susceptible. • Plant growth stage can also affect disease progress, which is more rapid on young, succulent plant tissues**. (Gauthier and Gauthier)**
Pumpkin yellow vein mosaic	*Pumpkin yellow vein mosaic virus (PYVMV)*	Whitefly *Bemisia tabaci*	**Persistent manner**	• Yellow vein mosaic disease symptoms occur frequently in pumpkin in India. • Diseased plants show vein yellowing, which sometimes coalesces to form chlorotic patches. • Infected plants are stunted and flowers drop prematurely, greatly reducing yields**. (Muniyappa *et al*., 2005)**

Yellow vein mosaic of bitter gourd	Bitter gourd yellow mosaic virus (BGYMV)	White fly *Bemisia tabaci*	**Circulative, Non propagative**	• This disease attains significance because the virus causing this disease is capable of attacking the crop at all stages. • Small irregular yellowish patches are seen on the leaves. • Some leaves show vein clearing in one or two lobes of the leaf and severely infected plants show reduction in leaf size and elongation and/or suppression of one or two lobes.
Yellow mosaic of ridge gourd	*Tomato leaf curl New Delhi virus (ToLCNDV)*	Whitefly *Bemisia tabaci.*	**Circulative, non-propagative manner**	• Gourd plants exhibited mosaic with light chlorotic region on the leaf lamina, upward curling, blisters on leaves, reduction in leaf size, yellowing, cupping and at severe infection, stunting of ridge gourd plants **(Patil *et al.,* 2017)** • Mottling with dark green and yellow colour. • Blisters and raised surface on leaves. • Stunting with negligible or no flowering and fruiting or very small fruits.
Leaf curl of ridge gourd	*Tomato leaf curl New Delhi virus(ToLCNDV)*	Whitefly *Bemisia tabaci.*	**Circulative, non-propagative manner**	• The infection of ToLCNDV on cucurbits exhibits characteristic symptoms including yellow mosaic,

				reduction of intermodal length, severe curling, vein swelling, rough skin and reduced fruit setting **(Moriones *et al*., 2017)**
Beet western yellows/ Turnip yellows	Beet western yellows virus (BWYV)	Aphid *Myzus persicae*	**Circulative, non-propagative manner**	• The beet yellowing disease appears in circles in the fields. • The leaves thicken and become brittle. • Symptoms first form limited areas of infection in the fields in July and August and then rapidly spread throughout the entire field. • Beet western yellows infection varies depending on the affected species and the virus strain, making diagnosis tricky. • Most plants infected with BWYV don't show any signs at first. • Red, blue, purple, or black discolorations that start at the tips and edges of leaves appear. • Infected leaves feel thick and brittle, and they may curl upward. Stunting is common, and leaf crinkling may occur.
Turnip phyllody	Phytoplasmas *Candidatus phytoplasma asteris*	Jassid *Orosius albicinctus.*	**Persistent manner**	• The diseased plant assumes a dull grey to light violet colouration.

				• The symptoms of the disease appear at the time of flowering when all the floral parts become green violet and leafy. • The sepals and petals become green thick knob headed leaves. • Generally, the whole plants show symptoms of the disease. If the infection occurs at an early stage of growth in the nursery then the whole plant is affected. **(NHB, Bangalore)** **National Horticulture Board**
Turnip mosaic	Turnip mosaic virus (TuMV)	Aphid *Myzus persicae Brevicoryne brassicae Lipaphis erysimi*	**Non-persistent manner**	• Young leaves of infected cauliflower p lants show chlorotic ring spots followed, as the leaf ages, by yellow or brownish spots surrounded by circular or irregular necrotic rings. • Generally, these occur in the vicinity of the leaf veins. • Leaf blight appears in infected sections when many lesions coalesce. • Outer leaves of infected cabbages may show ring spot pattern or appear more uniformly necrotic, but, as the leaves age, a chlorotic colour almost replaces

				the normal green tissue. • In white cabbage, the occurrence of internal necrotic lesions, sunken and coalescent, has been correlated with the presence of field symptoms of turnip mosaic virus. **(Caciagli, 2008)**
Turnip crinkle	Turnip crinkle virus(TCV)	flea beetles (*Psylloides sp., Phyllotreta sp.)*.	**Non persistent manner**	• The disease is characterized by crinkling of leaves. • The infected leaves show rugged, appearance, develop yellow patches and are brittle. • The yellow patches coalesce and become necrotic with age of the plants. • Later on, the affected leaves begin to die and wither away. • Severely affected plants show a stunted growth with a rosette appearance. **(NHB, Bangalore)**
Turnip yellow mosaic	Turnip yellow mosaic virus(TYMV)	Flea beetles *Phyllotreta* spp and *Psylloides* spp	**Semi persistent manner**	• This virus only infects crucifers. • In cauliflower, symptoms begin as vein clearing but subsequently develop into permanent yellow patches on older leaves. • Symptoms on Chinese cabbage develop into bright yellow and

				dark green mosaic patterns. • During cool weather, infected plants remain stunted. Symptoms are mild in other brassicas
Lettuce mosaic	Lettuce mosaic virus (LMV)	Lettuce Aphid, cotton aphid (*Aphis gossypii*), the potato aphid (*Macrosiphum euphorbiae*), and the green peach aphid (*Myzus persicae*)	**Non-persistent or semi persistent manner**	• LMV infected plants usually show vein clearing, yellow mottling, bronzing and stunted growth. • Symptoms are quite variable and depend on the cultivar, the environmental conditions, and the developmental stage at which the plant became infected **(Dinant and Lot, 1992)** • In the field, this can be seen as severe stunting, yellow coloration, failure to head normally, and downward curling of outer leaves.



Little leaf of Brinjal



Brinjal leaf curl virus disease



Yellow vein mosaic virus disease



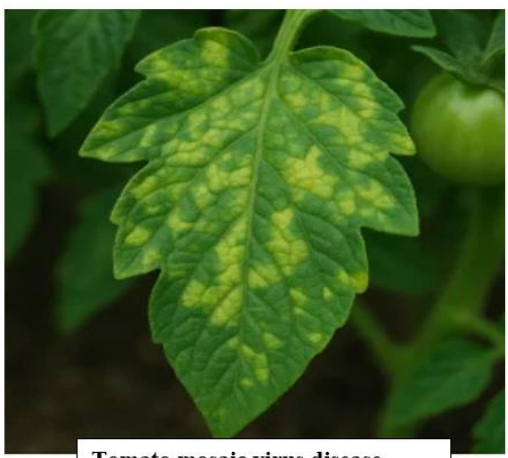
Okra enation of leaf curl virus disease



Tomato leaf curl virus disease



Tomato ring spot virus disease



Tomato mosaic virus disease



Tomato necrotic spot virus disease



Iris yellow spot of Onion and Garlic disease



Chilli leaf curl disease



Potato leaf roll disease



Witches broom of Potato



Potato scab disease



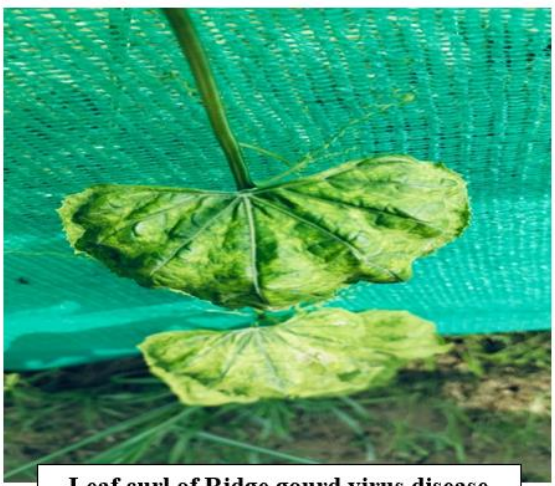
Cauliflower mosaic virus disease



Yellow vein mosaic of Bitter gourd virus disease



Yellow vein mosaic of Ridge gourd virus disease



Leaf curl of Ridge gourd virus disease



Turnip yellow mosaic virus disease

Exercise -11

To study about the different diseases of Fruit crops transmitted by insects.

Disease	Causal organism	Vector	Virus vector relationship	Symptoms
Leaf curl of Papaya	Papaya leaf curl virus (PaLCuV)	White fly *Bemisia tabaci*	**persistent-circulative nonpropagative manner**	• Papaya leaf curl disease was easily found in papaya gardens in major papaya growing states of India especially in Andhra Pradesh, Karnataka, Tamil Nadu, Delhi and Uttar Pradesh states. • Mostly the young leaves are affected. • The infected papaya plants showed downward **curling and crinkling** of leaves accompanied by **vein thickening**. • The more seriously infected plants tend to develop **twisted petioles** and stunting in field. • Diseased papaya plants either **no fruits** or produced small and distorted fruits.
Papaya mosaic	Papaya mosaic virus (PapMV)	Aphid *Aphis gossypii* and *Myzus persicae*	**Non-persistent manner**	• Infection with PapMV causes mosaic discolorations on foliage and stunting of papaya trees. • In **severe infestation**, defoliation progresses upward until only a small tuft of leaves remains at the crown and yellow to tan in colour. • On the stems and petioles of infected plants are found pinpoint-size spots. • On the fruit, symptoms may be manifested in all stages of maturity. Small, dark-green ring spots, 1 by 16 inch in diameter, have been observed on fruits as young as 2

				weeks old. • Spots increases in diameter as fruit matures. • On ripe fruit, there is no mottling of colours as found in papaya ring spot disease.
Papaya ring spot virus disease	Papaya ring spot virus (PRSV)	Aphid *Aphis craccivora* and *Aphis gossypii*	**Non-persistent manner**	• Typically characterized by the production of ring spot symptoms on fruit of infected papaya trees **(Jensen, 1949)**. • In addition to ring spots, PRSV produces a range of other symptoms such as leaf mosaic chlorosis, water-soaked oily streaks on the petiole and upper part of the trunk, distortion of young leaves that sometimes results in shoestring-like symptoms that resemble mite damage, stunting of infected plants, and flower abortion. • Fruit production can be severely decreased, and fruit sugar levels reduced by 50% or more.
Bunchy top of papaya	Rickettsia-like phloem limited bacteria	Leaf hoppers *Empoasca papaya and Empoasca stevensi*	**Persistent manner**	• Young leaves of infected plants show faint mottling on upper leaves, then chlorosis and marginal necrosis, and become rigid. • Internodes become progressively shorter, further apical growth stops, and the plant develops a “bunchy” top. • Older leaves may fall off, any fruits that are set are bitter, and the entire plant may die. **(George N. Agrios)** • Oily appearing spots are often present in the upper parts of stems and in petioles. • If fruits are set on infected plants, their flavour may be bitter due to the disease. **(Davis *et al*,, 1998)**
Banana bunchy top	Banana virus 1 (or) Musa virus 1	Banana aphid *Pentalonia*	**Persistent-circulative (capoor,1996)**	• New leaves emerge with difficulty, are narrower than normal, are wavy rather than flat, and have yellow (chlorotic) leaf margins.

		nigronervosa		• They appear to be "bunched" at the top of the plant, the symptom for which this disease is named. • Severely infected banana plants usually will not fruit, but if fruit is produced, the banana hands and fingers are likely to be distorted and twisted. • These symptoms are referred to as "**Morse Code Streaking**" because the streaks are irregular and resemble a series of "dots" and "dashes." and "**Green J-Hooks."** Because of dark green, hook-like extensions of the leaf lamina veins can be seen in the narrow, light-green zone between the midrib and the lamina. The short hooks point down along the midrib toward the petiole. **(Nelson, 2004).** • Leaves produced are progressively shorter, narrow, and brittle in texture; these bunch together at the top and hence provide the name of the disease. • Occasionally, bracts of male flower buds turn to a leafy structure and exhibit dark green dots and streaks**. (Thomas, Iskra-Caruana, and Jones, 1994).** • Plants infected at a later stage do not normally show leaf symptoms, but dark green streaks can be seen on the tips of the bracts.
Banana streak virus disease	Banana streak virus (BSV)	Mealy bug *Planacoccus citri*	**Semi-persistent**	• BSVs infect different species of Musa and the natural and synthetic hybrids. • Most isolates produce discontinuous yellow dots/streaks that turn necrotic on the leaves, and also pseudo-stem splitting. • Generally, symptoms are erratically distributed on the plant and not shown on all leaves.

				• Some isolates immediately produce stunting with severe necrotic streaks resulting in cigar leaf necrosis and leading quickly to the death of the plant **(Thangavelu, Selvarajan, and Singh, 2000)**. • Symptomatic and symptomless stages alternate in infected plants but virus can be detected at all stages.
Banana mosaic virus disease Also called as 'infectious chlorosis'	cucumber mosaic virus (CMV)	Aphids *A. gossypii, A. craccivora, R. maidis, R. prunifolium, and Myzus persicae*	**Non-persistent manner**	• It causes variable symptoms from mild chlorosis to severe chlorotic streaks that are similar to the symptoms of BSV infection. • Most common CMV strains do not produce severe symptoms or cause significant damage on banana. However, some severe strains cause severe necrosis in pseudo stems (heart-rot) and even plant death. (**Bouhida and Lockhart, 1990).**
Banana bract mosaic disease	Banana bract mosaic virus (BBrMV)	*Pentalonia nigronervosa, Rhopalosiphum maidis* and *Aphis gossypii.*	**Non-persistent manner**	• BBrMV causes characteristic spindle-shaped, purplish streaks on bracts, pseudo stems, midribs, peduncles, and even fruits. • Bunches from infected plants unusually contain a long or very short peduncle and in some cultivars, such as Nendran, the leaves appear as "traveller's palm" plant. • Necrotic streaks on fruits, leaves, pseudo stems, and midribs have also been recorded. **(Selvarajan and Jeyabaskaran, 2006).** • Yield losses of between 30% and 70% have been recorded in India and the Philippines.
Katte disease of Cardamom/ cardamo	Banana virus 1 (or) Musa virus 1	Banana aphid *Pentalonia nigronerv*	**Non-persistent manner**	• The first visible symptom appears on the youngest leaf of the affected tiller as slender chlorotic flecks measuring 2- 5 mm in length. Later these flecks develop into pale green

m mosaic disease		*osa*		discontinuous stripes. • These stripes run parallel to the vein from the mid rib to leaf margin. • All subsequently emerging new leaves show characteristic mosaic symptoms with stripes of green tissue almost evenly distributed over the entire lamina **(Uppal, Varma and Capoor 1945).** • Often mosaic type of **mottling** is seen on the, leaf sheaths and young pseudo stems. • The infection is systemic in nature and it gradually spreads to all the tillers in a plant. • In the advanced stage the affected plants produce shorter and slender tillers with few shorter panicles and degenerate gradually.
Cardamom vein clearing virus ('kokke kandu')	Cardamom vein clearing virus (CdVCV)	Cardamom aphid *P. nigronervosa f. caladii*	**Persistent manner**	• The first symptom of the disease is continuous or discontinuous vein clearing. Later these turn necrotic followed by shredding of lamina. • All the new shoots are greatly stunted with yellow mottling on pseudo stems. • Often light **yellow mottling** is clearly visible on panicles and capsules. • Plants in advanced stages of infection produce, distorted leaves and capsules. During slow growing months the new leaf' gets entangled in the old leaf and forms characteristic hook like tillers and hence the name 'kokke kandu'. • Rosetting of leaves and cracking of capsules are also seen in advanced stages of infection. In r summer, the newly infected plants show 1 only faint discontinuous vein clearing symptoms. • However, mottling on pseudo stem is clear during summer months also. **(Venugopal, 1995)**

Grapevine leaf roll	Grape vine leaf roll virus (or) Grape vine virus A and Grapevine virus B	Grapevine mealy bug *Maconellicoccus hirusutus*	**Semi-persistent manner**	**Leaves** Leafroll symptoms include downward rolling of leaves and reddening (red varieties) or yellowing (white varieties) of the leaf tissue between the main veins. • The discolouration may be less obvious in white varieties. • The main veins may remain green, although in some varieties the discolouration affects all of the leaf tissue. **Fruits** • Effects on fruit quality can include reduced colour in red varieties, reduced aromas, reduced sugars and increases in titratable acidity. • The ripening of fruit may be delayed. **Vine growth** • Leafroll-affected grapevines may have reduced growth resulting in smaller canopies. • Leaf roll disease may result in a decline of grapevines over time and reduce the lifespan of affected vineyards. **(Factsheet, 2014)**
Grapevine vein clearing	Grapevine vein clearing virus (GVCV)	Grape aphids *Aphis illinoisensis*	**Semi-persistent manner**	• The leaves of diseased vines are small, deformed and rolling downward with translucent veins and mosaic patterns. • The diseased vines have short internodes, brownish abnormal berries, and eventually loss productivity as a result of severe vine decline. **(Beach *et al.*, 2017)**
Grapevine fan leaf	Grapevine fan leaf virus (GFLV)	Nematode *Xiphinema index*	**Semi-persistent manner**	• The symptoms of GFLV are "distortion of leaves and may cause unusual chlorotic (yellow) patterns on leaves, such as a yellow mosaic or yellow veins."**(Stephen and jordan)** • Plants infected with GFLV also will have a reduced size and the fruit

				will be softer when compared to fruit from healthy plants. • The leaves will be "severely distorted, asymmetrical, cupped and puckered, and exhibit acute dentations", these symptoms tend to look like a fan, hence the name fan leaf virus. • The canes may also show signs of abnormal branching, double nodding, and short internodes. • Affected vines can also show signs of yellow mosaic which may affect all parts of the vine. • The berries of the plant have a reduced yield and are smaller. They also have irregular ripening times.**(Jonathan *et al*., 2011)**
Grapevine red blotch	Grapevine red blotch virus (GRBV)	The three-cornered alfalfa hopper (*Spissistilus festinus)*	**Circulative, non-propagative manner**	• The foliar red blotch symptoms started in the middle or at the edges of leaf blades and coalesced as the season progressed. • Initially, symptoms were largely restricted to the basal leaves but leaves in the middle of the shoots became symptomatic as the season progressed. • In symptomatic leaves, the primary, secondary, and tertiary veins often became red, and the veinlets within blotchy areas also turned red. • Extensive testing for all known leaf roll-associated viruses revealed no infection by any of the leaf roll-associated viruses in symptomatic grapevines **(Calvi, 2011)**
Pierce's disease	*Xylellea fastidiosa* Xylem inhibiting bacteria	Leaf hopper (Glassy-winged sharpshooter) (*Homalodisca coagulate*	**Persistent Propagative**	• In disease-susceptible vines, the bacteria can multiply to such levels that they cause vascular blockage, either directly or via defensive gums produced by the vine. • The vascular blockage ultimately leads to the characteristic disease symptoms including drying or scorching of leaves in irregular

		) Blue green (*Graphocephala atropunctata*) Green (*Draeculacephala minarva*) Red headed (*Carneocephala fulgida*)		patterns in sections or along margins of the leaf blades. • Additionally, leaf blades abscise leaving petioles attached to the cane (matchsticks), periderm develops irregularly (green-islands), and fruit clusters shrivel. • Pierce's disease may kill the vine within one to two years. • Symptoms first develop during the latter part of the growing season after the bacteria have colonized the vine. • Drought conditions and hot temperatures speed symptom development. • Spring symptoms develop if infection occurred the previous year. This is called chronic infection. Spring symptoms appear as delayed bud break, stunted growth, and zig-zag internodes on developing shoots. • The infected vine may die within a year of infection or vines may persist for five or more years. **(Pearson and Goheen, 1988)**
Citrus greening (or) Huanglongbing (HLB)/ Vein Phloem Degeneration	*Bacteria Candidatus Liberibacter*	Citrus psyllid *Diaphorina citri*	**Propagative, circulative and persistent manner**	**Leaf symptoms** • Blotchy mottling patterns on the leaves are asymmetrical using the mid-rib as a central line, which is by far the inevitable diagnostic greening symptom, and it is between said as severe infection and incidentally similar to the sign of Fe deficiency when leaves turn discoloured yellow **(Inoue *et al.*, 2020)** • The blotchy mottle is mainly present in young or mature leaves anywhere in the tree canopy. • For greening, vein corking and yellow veins alone are not diagnostic. • If present, however, check the tree

				canopy for blotchy mottle symptoms as well: mid-vein, "corky" mid-veins/under-rib, interveinal chlorosis, bright yellow shoots among a green canopy, pronounced/prominent. **Fruit symptoms** • The colour of the stylus end shows the yellow/orange colour when healthy fruits reach maturity, and the green colour is associated with the peduncle end. • While fruits are affected by HLB disease, on the other hand, the peduncular end is yellow-orange and the stylus end is still green **(Bové, 2014)** • The fruit can be lopsided, oblong, distorted, or small and green. Inversion of fruit colour formation (fruit yellowing from top to bottom on citrus varieties of orange colour). • A small number of sour oranges are tolerant among all varieties, and their symptoms are not as dreadful as compared to others. • Fruit dropping starts in its early stage of life due to having symptomatic fruits in infected trees, which means immature fruits are falling off and sub-sequencing **(Dala-Paula *et al*., 2019).**
Citrus tristeza Tristeza = 'sadness' in Portuguese	Citrus Tristeza virus (CTV)	Brown citrus Aphid *Toxoptera citricida* *Aphis gossypii*	**Semi-persistent**	• Stunting, leaf cupping, vein clearing, chlorotic leaves, stem pitting and reduced fruit size are common symptoms observed on susceptible hosts. • The decline results from the physiological effects of the virus on the phloem of the susceptible rootstock just below the bud union. • Trees that decline slowly generally have a bulge above the bud union, a brown line just at the point of bud

				union, and inverse pinhole pitting (honeycombing) on the inner face of sour orange root stock bark **(IPPO)**
Citrus stubborn disease	*Spiroplasma citri*	Leaf hoppers *Circulifer tenellus Scaphytopius nitrides Neoaliturus haemoceps*	**Persistent-propagative**	• It is hard to diagnose but reduces yield, quality, and marketability of fruit dramatically. • Infected trees grow upright but are stunted. There is less fruit and it is smaller, lopsided, green, and sour, bitter, and unpleasant. **(George N. Agrios)** • Flowering can occur at any time of year, but the fruits are of poor quality, and their number declines over time. **(Chapot, 1959)** • Multiple axillary buds, a large number of shoots, and erect, bunchy growth with short internodes are all signs of aberrant growth. • On severely damaged trees, twigs become stunted and die. • Infected trees have smaller leaves than healthy trees. • The leaves might have a healthy or diseased appearance (mottled, cup-shaped, distorted in different ways, and pinched in near the tip). **(Sagouti,2022)**
Concentric ring blotch of Citrus	Citrus grey mite *Calacarus citrifolii*	--	**Propagative, Persistent**	• The symptoms found on the Navel orange may be taken as being typical of the sweet orange in general. • Small, light-green spots, slightly raised in the centre, appear on the tender, young leaves; they increase in size, and exhibit a more or less concentric zoning. • The mature spot may be round or irregular in outline, and varies from about k inch to an inch or more in diameter. • There is often a brown spot in the Centre, due to the lemon (i.e. budded lemon). **(Doidge and van**

				der plank, 1914)
Citrus leprosis	Citrus leprosis virus (CiLV)	Mite *Brevipalpus Phoenicus*	**Circulative-propagative manner**	• The main symptoms of the disease include lesions on fruits, leaves, and twigs or small branches, causing premature fruit drop, defoliation, and death of the twigs or branches leading to serious tree decline. • Leprosis is a highly destructive disease of citrus, wherever it occurs. **(Rodrigues, 2003).** • *Brevipalpus* mites inject toxic saliva into fruits, leaves, stems, twigs, and bud tissues of numerous plants including citrus. • Feeding injury symptoms on selected plants include: chlorosis, blistering, bronzing, or necrotic areas on leaves • These feeding sites become progressively necrotic, darker in colour, and eventually develop into irregular scab-like lesions on affected fruit. • Russeting and cracking of the fruits of other plant hosts are reported. Stunting of leaves and the development of *Brevipalpus* galls on terminal buds were recorded on sour orange, Citrus aurantium L., seedlings heavily infested with *B. californicus* in an insectary. **(Childers *et al*., 2003)**
Mango malformation	Fungus *Fusarium mangiferae*	Eriophyid mite *Aceria mangiferae*	**Semi-persistent**	• Abnormal, compact development of shoots and flowers are common signs of mango malformation disease. Both normal growth and mango malformation disease–affected growth may be present on a plant at the same time. • **Shoots -** The leaves are significantly smaller than those of healthy plants and re-curve towards the stem giving a squat, bunchy-top appearance. • **Flowers -** Affected flower stems or

				panicles are thickened and highly branched, producing up to three times the normal number of flowers. • **Mango fruit** -There are no impacts on human health from mango malformation disease and mango fruit is safe to eat. **(Bio security Queensland)**
Peach mosaic virus disease	Peach mosaic virus (PMV)	Eriophyid mite *Eriophyes insidiosus*	**semi-persistent**	• Symptoms of peach mosaic include mosaic on leaves in the spring and early summer, vein clearing, colour break and deformation of petals, stunted leaves, fruit deformity, and dwarfing of the twigs **(Stout, 1939)**. • Symptoms are milder in criollo varieties than in other commercial peaches **(Oldfield *et a*l., 1995).** • Most freestone cultivars show strong symptoms, while clingstone cultivars express only mild symptoms. **(Pine,1976)**
Gooseberry vein banding	Gooseberry vein banding associated virus(GVBaV)	Aphids *Aphis grossulariae, Nasonovia ribisnigri and Hyperomyzus spp.*	**Semi persistent manner**	• The typical disease symptoms include pale-yellow streaks along leaf veins of infected plants which are more pronounced in spring when first leaves expand**.(Lamovsek *et al*., 2017)**
Fig mosaic disease	Fig mosaic virus (FMV)	Eriophyid mite *Aceria ficus*	**semi-persistent**	• Fig trees affected by FMD can show vigour reduction, and symptoms include chlorotic and yellowish spots, discoloration, deformation, and mosaic patterns on the leaves and fruits (**Preising *et al*., 2021**)
Cocoa swollen shoot virus disease	Cocoa swollen shoot virus(CSSV)	Several species of mealy bugs.	**Semi-persistent manner**	• Main symptoms include: leaf chlorosis (interveinal), root necrosis, red vein banding in young leaves, small mottled pods,

				and stem/root swelling followed by die-back. **(Dongo and Orisajo, 2007)** • The trees are usually killed within 3 to 4 years. • The development of root/stem swellings in infected plants. **(Asomaning and Lockard, 1964)**
Clover phyllody	*Phytoplasma trifolii*	Leaf hopper *Macrostel es cristata, Euscelis plebejus (Fallen)*	**Persistent manner**	The symptoms of disease in the plants infected can be characterized by • Slight flavescence or, at least, slight vein clearing of the apical leaves. • Growth inhibition accompanied by proliferation of axillary buds into thin shoots, • Virescence, phyllody and proliferation of flowers or inflorescences and • Marked reduction and deformation of leaves. **(MUSlL,1961)**
Mealy bug wilt disease of pine apple	Pine apple root wilt virus	Mealy bug *Dysmicoc cus brevipes*	**Persistent manner**	• This symptom does not develop in plants afflicted by "slow" wilt. • The wilting of leaves is divided into four stages: (1) Initial reddish coloration development in the inner leaves; (2) Inward curling of leaf margins, with a change from red to pink coloration of the wilted leaves; (3) The leaves development of a glossy appearance and (4) leaf tips becoming necrotic, and desiccating • Yellow chlorotic leaves than the red to pink discoloration seen in older varieties. • Below ground, the root system collapses and results in plant death. **Carter and Collins (1947).** • In both quick and slow wilt, the plant may die prematurely and may not produce any fruit. • It was observed that plants showed a recovery phenomenon later on,

				which was a quicker process in slow wilt than quick wilt, but the fruits produced were small. **Carter (1967).**
Yellow spot of pine apple	Tomato spotted wilt virus(TSWV) and capsicum chlorosis virus	Thrips *Thrips tabaci*	**Non-persistent manner.**	• Infection occurs on young crowns when they are still on the fruit or during the first few months after planting. • Small (2-5 mm), round, yellow spots appear on the upper surface of the leaves of young plants. • These spots fuse and form yellow streaks in the leaf tissue, which soon become brown and die. • The virus spreads to the leaves in the plant heart, causing the plant to bend sideways. • Infection eventually kills the plant so that the virus is not transmitted to subsequent plantings. • If the crown is infected while still on the fruit, the fruit dies from the top downwards. • Infections can occur through open blossoms causing the development of large, blackened cavities in the side of the fruit. **(Joy and Sindhu)**
Bacterial heart rot of pine apple	*Erwinia chrysanthemi*	Beetles *Haptoncus ocularis* and *Carpophilus foveicollis*	**Semi persistent manner**	• Water-soaked lesions first appear on the white basal portion of the leaves of the central whorl. • As they develop, the green mid portion of the leaves assume an olive green and bloated appearance, symptoms that distinguish bacterial heart rot from *Phytophthora* heart rot **(Lim, 1985).**
Pear decline	*Candidatus Phytoplasma pyri* .	pear psylla *Cacopsylla pyricola*	**Persistent manner**	• The first symptom is seen in autumn when the leaves of affected trees develop a premature red colour followed by early leaf fall. • The second symptom is seen in the following spring when leaves remain small and pale, there being

				little or no shoot growth and no fruit production. Often, a necrotic line is visible in the inner part of the bark at the stock-scion union • The severity of the spring symptoms can vary from death or severe stunting to their complete absence • **Westwood and Cameron (1978)** suggested that if disease trees are not exposed to repeated infestations of psyllids the symptoms became milder after some dormant seasons. The disease needed repeated infection by the vectors especially in trees grafted on quince rootstocks • A typical diagnostic symptom of pear decline is a dark phloem ring immediately below the graft union in bark sections from infected trees visible by microscopic examination of stained transverse sections **(CABI plant wise plus)**
Cherry mottle leaf	*Cherry mottle leaf virus (CMLV)*	Bud mite *Eriophyes inaequalis*.	Non persistent manner	• CMLV occurs naturally in sweet cherry, ornamental flowering cherry, peach, and apricot. • The most distinctive symptoms include chlorotic mottling and leaf distortion. • The disease affects fruit quality and quantity and is the most severe disease on some cherry cultivars in some regions. **(James, 2018)**
Raspberry ring spot	*Raspberry ring spot virus*	Nematodes *Longidorus sp*	**Semi persistent manner**	• Infected plants are usually patchily distributed in crops, reflecting vector distribution. • Those that survive produce stunted and brittle shoots which have rolled leaves and show dieback progressively from the tip, accompanied by necrosis. • In less susceptible cultivars, such as Malling Jewel, Malling Enterprise and Malling Notable,

				symptoms appear on the leaves of new shoots in spring, but are mild or absent on the leaves of fruiting canes. • Young, expanding leaves develop a conspicuous, yellowish-green, ring spot or oak-leaf pattern; chlorotic blotches and a net-like chlorosis along the smaller veins may also be present. • Some necrosis and dieback may occur. • Malling Promise develops few symptoms and does not die back; Lloyd George and Malling Landmark are immune to the common strain but are susceptible to the Lloyd George yellow blotch strain **(Murant, 1970b).**
Strawberry latent ring spot	Strawberry latent ring spot virus (SLRSV)	Nematode *Xiphinema diversicaudatum* *Xiphinema coxi*	**Persistent manner**	• The disease is usually latent in strawberries and other fruit crops, i.e. no symptoms are seen. Some strawberry cultivars show varying degrees of mottling and decline. • **Pic credit: Nopphadon Pontharangsee**



Papaya leaf curl virus disease



Papaya mosaic virus disease



Bunchy top of Papaya



Banana Bunchy top



Banana streak virus disease



Banana bract mosaic virus disease



Katte disease of Cardamom



Grapevine leaf roll virus disease



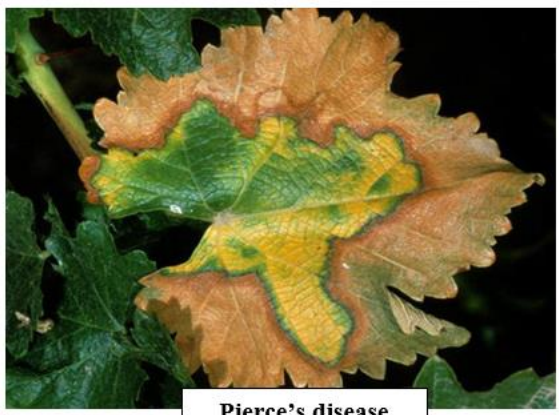
Grape vine vein clearing disease



Grapevine fan leaf virus disease



Grape vine red blotch virus disease



Pierce's disease



Citrus Tristeza virus disease



Citrus leprosis virus disease



Fig mosaic virus disease



Cocoa swollen shoot virus disease



Clover phyllody disease



Strawberry latent Ring spot virus disease

Exercise -12

To Study about the different diseases of Sugarcane, Tobacco, Cotton transmitted by insects

Disease	Causal organism	Vector	Virus vector relationship	Symptoms
Sugarcane mosaic disease	Sugarcane mosaic virus	Aphids *Dactynotus ambrosiae* , *Hysteroneura setariae*, *Longiunguis sacchari*, *Rhopalosiphum maidis* and *Toxoptera graminum*	**Non-persistent manner.**	• The symptoms of mosaic disease caused by SCMV, SrMV and SCSMV are similar, especially in the middle and lower sections of new leaves. • In comparison to healthy leaves, there are many irregular yellow and green inlays, stripes, or mottles alternate with parallel veins on symptomatic leaves, more clearly visible against the sunlight. • Some are mostly normal green with only a few narrow pale-yellow streaks, some show very obvious whole leaf chlorosis, and the seriously infected leaves turn yellow or yellow white, leaving only a few green islets or a small amount of red punctate necrosis, or the tips of new leaves are abnormally twisted. • Some varieties show cryptic or indistinct phenomena at a high temperature, but the symptoms recur as the temperature drops **(Koike and Gillaspie 1989)**

Yellow leaf disease in sugarcane	Sugarcane yellow leaf virus (ScYLV)	Sugarcane aphid: *Melanaphis sacchari.*	**Persistent, circulative, and non-propagative manner**	• The most characteristic symptom of YLD is a distinct yellowing of the lower surface of the leaf midrib on young leaves at the apex of the mature plants, which can extend laterally to the leaf lamina. • The yellowing of the midrib may turn **pink** or have a **reddish tinge** in some sugarcane varieties due to sucrose accumulation. • Older leaves show a red coloration of the midrib on the adaxial surface. Afterwards the leaf blade becomes bleached, proceeding from the tip toward the base of the leaf and tissue necrosis can eventually take place. • The yellowing can spread into the leaf blade and midveins can turn pink in severely infected plants • The lower surface of the midrib turns from green to bright yellow or pink or reddish. • Dwarfism of the terminal internodes may also be observed. • In severe cases, diseased plants are stunted and can be pulled easily. • The yellowing can spread into the leaf blade and mid-veins can turn pink in severely infected plants. • Leaf tips become yellow, then necrotic and necrosis may spread down the blade. • The disease infection results in reduction in sucrose content in stalks and accumulation of sucrose in leaf midribs and

				therefore yield losses**. (Naidu *et al*., 2021)**
Green grassyshoot disease in sugarcane	*Candidatus Phytoplasma sacchari*	Aphids *Rhopalosiphum maydis, Melanaphis sacchari and M. idiosacchari*.	**Non-persistent manner**	• The main symptom of GGSD is small, green, and profuse tillering at the base of the mature sugarcane stool. • These tillers do not exhibit any white leaves, in contrast to White Leaf Disease (WLD). • When the crop is ratooned, emerging shoots (if there are any) consist of very small, green profuse tillers which fail to develop into mature stalks. • Advanced infestations are characterized by very gappy ratoons and greatly reduced yields.
Sugarcane streak mosaic	Sugarcane streak mosaic virus (SCMV)	Leafhoppers *C. mbila* and *C. bipunctella.*	**Non-persistent manner**	• Infected leaves are covered with numerous small spots or streaks which are translucent, narrow and parallel to the veins. • After infection, the streaks are irregularly distributed and observed mostly on the lower part of the leaf blade. • These symptoms, however, tend to be uniformly distributed on all leaves once the virus is established in the plant. • The streaks are from 0.5 to 2 mm in width and vary in length from 0.5 mm to more than 2 cm. • The streaks observed on young leaves that develop from an infected cutting can be relatively wide, they coalesce and sometimes form a pattern of mosaic **(Storey and Thomson, 1961).**

Tobacco streak virus disease	Tobacco streak virus (TSV)	Thrips *Franklinothrips orizabensis*, *F. vespiformis* and *Thrips tabaci*	**Propagative, Persistent**	• TSV symptoms can show three distinct stages: 1: **The acute or necrotic stage** – local lesions appear as rings, solid necrotic spots, or diamond-shaped patterns. Sometimes the symptoms may disappear at a later stage. 2: **The early recovery stage** – new leaves develop which appear normal except for chlorotic veins and 3: **The chronic or late recovery stage** – the leaf is thicker than normal with a smoother texture and the tubular corolla splits with the bracts become separated, especially the upper half. • The symptoms are more severe and appear as large necrotic arcs, broken rings, lines, and dots around the necrotic secondary veins when the temperature is above 30°C. • Chlorosis of young leaves at the tip, discoloration, bronzing, necrosis, veinal chlorosis curling of leaves, and necrotic streaks on petioles, stem, and flowers, and dwarfing or stunting of plants are observed if infection occurs at an early stage. • Square drying and dropping are also observed under severe infection conditions, which depend on the abundance of infected pollen, parthenium population, thrips multiplication, and their movement. **(Sain *et al*., 2023)**
Tobacco mosaic virus disease	Tobacco mosaic virus	This virus (TobaMo) is not transmitted by insects, and	• Irregular mosaic pattern of dark and light green areas of the leaf, Stunting, malformation, distortion and puckering of leaves and growing tips. • Yellow-green mottling or mosaic pattern of light	

		it is transmitted by means of mechanical, direct contact with infected plant material or contaminated tools	green and dark-green areas on the leaves. • Nearly mature leaves that are infected may show ‘’**Mosaic burn**’’ with large and irregular, burned or necrotic areas on the foliage that can cause extensive damage to the crop. • Vein clearing, yellowing or streaking of leaves**. (Lucas,1975)**	
Leaf curl of tobacco	Tobacco leaf curl virus (TLCV)	White fly *Bemisia tabaci*	**Persistent manner (circulative).**	• Diseased leaves curl, become brittle, puckered, downward curling of margins with enations or leafy outgrowths on the under surface of leaves **(Osaki and Inouye, 1981).** • Leaves show vein clearing, abnormal vein thickening and twisting of petioles. • Internodes get shortened resulting in dwarfing of the plant. • Late infected plants do not show the severe symptoms although the top leaves look small and tend to curl inwards **(Nagarajan and Reddy, 1984).**
Cucumber Mosaic of tobacco	Cucumber Mosaic Virus (CMV)	Whitefly *Bemisia tabaci*	**Circulative manner**	• Typical mottling and mosaic patterns appear, sometimes accompanied by stunting and narrowing and distortion of the leaves. • Severe strains may cause interveinal discoloration and the oak-leaf pattern of necrosis on the lower leaves. • ‘Mosaic-burn’ or sun-scald frequently appears on the upper leaves of infected plants. Vein banding, inter venal yellowing, are accompanied with leaf blisters, shrivelled, chlorotic and necrotic lines causing filiform leaves. • Mixed infections are quite

				frequent in combination with other viruses **(Blancard *et al*., 1999).**
Tobacco Distorting Virus disease (TDV)	Tobacco Distorting Virus (TDV)	Aphids	**Persistent manner**	• The virus causes abnormal suckering, stunting and the leaves get mottled, puckered, distorted with rat-tails. • Only long midrib is seen without lamina at times. **(Gopalachari, 1984)**
Potato Virus Y in Tobacco	Potato Virus Y	Aphids *Myzus persicae*, *Myzus nicotianae*, And *Myzus persicae*	**Non persistent manner**	• This virus causes tobacco veinal necrosis or vein banding i.e. appearance of dark green bands along the brown necrotic veins. • Necrosis extends to the vascular region and plants die out of pith necrosis (**Gopalachari 1984).**
Tobacco ring spot virus disease	Tobacco ring spot virus (TRSV)	***Nematodes*** *Xiphinema americanum,* ***Thrips*** *Thrips tabaci,* ***grasshopper*** *Melanoplus differentialis*	**Non persistent**	• TRSV causes ring and line patterns on the foliage and stunting **(Gooding, 1991).**
Cotton Leaf Crumple Virus disease	Cotton Leaf Crumple Virus (CLCrV)	whitefly *Bemisia tabaci.*	***Persistent* and circulative *manner***	• Infected plants remain stunted with leaf crumpling, and downward curling accompanied by interveinal hypertrophy and foliar mosaic. • Characteristic symptoms include foliar discoloration and venial hypertrophy leading to puckering, crumpling, downward leaf curling, and shortening of internodes along with stunting of the host. • The symptoms are almost similar to CLCuD except for small vein darkening and vein thickening. Sometimes necrotic and mosaic-like patterns can also be seen on leaves. **(Sain *et al*., 2023)**

Leaf curl of cotton	Cotton leaf curl virus	White fly *Bemisia tabaci*	**Circulative, Persistent manner**	• Symptoms in cotton usually appear within 2–3 weeks of inoculation by *B. tabaci* and are initially characterized by a deep downward cupping of the youngest leaves. • This is followed by either upward or downward curling of the leaf margins, swelling and darkening of the veins as well as the formation of enations on the veins, which frequently (dependent on variety) develop into cup-shaped, leaf-like structures. • Under severs attack of the disease, leaves curl downward or upward with stunted plant growth due to reduction of inter nodal distance. • The appearance of the disease at seedling stage seriously retards the flowering, boll formation, maturation, and seed cotton yield and fibre quality. • The virus causes vein thickening followed by formation of veinal net on under surface of leaves and a few exhibited enations. • The infected leaves curl upward; the diseased plants remain stunted with considerable loss in yield. **(Singh *et al*., 1998).**
Cotton Virescence/ cotton leaf roll dwarf disease	cotton virescence phytoplasma	The brown leafhopper/ jassids *Orosius cellulosus*	**Circulative, non-propagative manner.**	• Virescence-infected plants exhibit symptoms that vary according to growth stage and time of infection. • Infection at an early stage of growth results in cessation of internode elongation, reduction in leaf size, and stunting (about two-thirds of normal plant height). • The entire inflorescence is

				converted into phyllody or malformation, like leaves is twisted, rolled with abnormal colour, leaves closely arranged on the top of the stem, with very 36 short internodes. • The stem shows stunting or resetting or witches' broom symptoms. • The whole plant shows dwarfing, resetting, or elongation with early senescence. • Infections that occurred later in the season caused characteristic symptoms, such as witches' broom. • Roots become hairy. **(Sain *et al.*,2023)**



Sugarcane mosaic virus disease



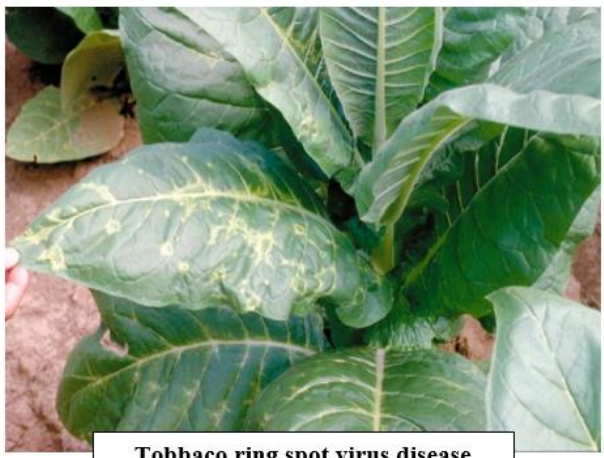
Yellow leaf virus disease



Sugarcane Streak mosaic disease



Leaf curl of Tobbaco virus disease



Tobbaco ring spot virus disease



Cotton leaf curl virus disease

Exercise -13

To study about different diseases of Oilseeds transmitted by insects

Disease	Causal organism	Vector	Virus vector relationship	Symptoms
Peanut rosette	Groundnut rosette virus (GRV)	Aphid *Aphis craccivora*	**Non-persistent manner**	• Three types of rosette have been recorded. 1. **Chlorotic rosette,** which is prevalent throughout Africa, is characterized by stunted plants with chlorotic, twisted, and distorted leaflets. Yield from early infected plants is severely reduced. **2. Mosaic rosette** is recorded only in eastern, central, and southern Africa. Younger leaflets show conspicuous mosaic symptoms. **3. Green rosette** currently occurs only in western Africa. Symptoms resemble those of peanut clump. Young leaves show mild mottling. Older leaves are dark green, reduced in size, and show downward rolling of leaflet margins. Plants are severely stunted. **(Subrahmanyam *et al*., 1992)**
Peanut stripe disease	Peanut stripe virus (PStV)	Aphid *Aphis craccivora, Aphis gossypii, Myzus persicae Rhopalosiphum padi Aphis glycines*, *Aphis citricola* and *Hysteroneura setariae*	**Non-persistent manner**	• The initial symptoms appear as chlorotic flecks or rings on young leaves which persisted in the older leaves. • The plants are slightly stunted. Subsequently, the older leaves show symptoms with mild mottle, blotch, stripe, chlorotic ring mottle, chlorotic line pattern, oak leaf pattern, or necrosis **(Wongkaew and Dollet 1990).** • The symptoms normally persist

				throughout plant development. • The "stripe" (V-shaped pattern) and "necrotic" islands, which are seen less often, can severely stunt the plants if they infect them early.
Peanut bud necrosis	Tomato spotted wilt virus (TSWV)	Thrips *Frankliniella schultzei* and *Thrips palmi*	**Persistent-propagative,**	**Primary symptoms** • Symptoms first appear on young leaflets as faint chlorotic spots or mottling that may develop into chlorotic and necrotic rings and streaks. • Occasionally, the leaflets may show a general chlorosis with green islands. • Petioles bearing fully expanded leaflets with initial symptoms usually become flaccid and droop. • Necrosis of the terminal bud soon follows. • The bud necrosis symptom is common on crops grown in the dry (summer) and rainy seasons in India, indicating that this symptom is probably associated with high temperatures. • If bud necrosis occurs on plants less than 1 month old. Total necrosis of the plant may follow. • Necrosis on older plants usually spreads only to the petiole, or to the portion of the stem immediately below the necrotic terminal bud. • In late-infected runner type groundnuts, a few branches may show mild ring spots or necrosis of the bud and then the whole plant turns yellow, wilts, and sometimes dies. **Secondary symptoms** • The stunting and proliferation of axillary shoots are common secondary symptoms of BND. • Leaflets formed on these axillary shoots show a wide range of symptoms including reduction in

				size, distortion of the lamina, mosaic mottling, and general chlorosis. • Rarely, the lamina is reduced to the midrib, giving the leaflet a "shoe string" appearance. • These secondary symptoms are most common on early-infected plants, giving them a stunted and bushy appearance. • Only a few branches on late-infected plants may show these symptoms. **(Information bulletin, ICRISAT)**
Peanut spotted wilt	Tomato spotted wilt virus (TSWV)	The tobacco thrips (*Frankliniella fusca*) and western flower thrips (*Frankliniella occidentalis*)	**Persistent and propagative manner**	• Initial symptoms may appear on TSWV-infected peanuts as early as 21 days after the seedlings emerge. • The earliest symptoms of the disease are brown speckles on the underside of the first leaf below one or more terminal buds along with chlorotic (yellow) ring-spotting and mottling on the upper side of the leaf. This first symptomatic leaf may also be wilted or flaccid. • Brown, necrotic spots or streaks may also be seen on the leaf petiole, stem, and at times on the terminal bud. • These spots may develop into a shoot dieback that may ultimately kill the plant. • New leaves are about half their normal size, crinkled, and display a range of symptoms including chlorosis, concentric chlorotic ring spots, and ring spots with green centres, chlorotic line patterns, and general mottling. • A downward twisting of leaf petioles and some terminals, a characteristic symptom of this disease, can also be seen at this

				stage.
Peanut stem necrosis virus	Peanut stem necrosis virus (PSNV)	Thrips *Frankliniella schultzei* and *Scirtothrips dorsalis*	**Persistent manner**	• Initial symptoms appear as large necrosis lesion on young quadrifoliate leaves, which coalesce and cover the entire leaflet followed by the necrosis of the stem below the necrotic leaves. • If young plants (less than 1 month old) are affected, the entire plant is often necrotized, whereas in the case of older plants, one or more branches will have necrosis. • These plants are stunted and do not show any axillary shoot proliferation. • Majority of pods also will have necrotic spots, and in severe infection, the pod size will be reduced and kernels will become not marketable.
Indian peanut clump virus	Indian peanut clump virus (IPCV)	The obligate fungal parasite *Polymyxa graminis*	**Persistent manner**	• Plants affected by clump disease are conspicuous in the field because of their severe stunting and dark green appearance. • Initial symptoms appear on young leaflet as mottling, mosaic and chlorotic rings, but later turn dark green with or without faint mottling as the leaves mature. • Early infected plants become severely stunted. Late infected plants may not show conspicuous stunting but appear dark green with faint mottling on younger leaflets. • In late infected plants, clumping may be restricted to few branches. Infected plants become bushy and produce several flowers. • Early infected plants may not produce any pods and late infected plants may produce poorly developed pods. **(Reddy *et al*., 1988).**

Peanut stunt	Peanut stunt virus(PSV)	*Aphids* *Aphis craccivora, A.spiraecola* and *Myzus persicae*.	**Non persistent manner**	• Symptoms vary depending on the host plant and the strain of the virus. • In groundnuts, there are various degrees of stunting, shortening of the petioles, reduced leaf size, mild mottling and malformation of pods. • Seeds from infected plants appear deformed, frequently with a split pericarp wall, and have poor viability.
Peanut green mosaic virus disease	Peanut green mosaic virus(PeGMV)	*Aphids* *Aphis craccivora* *Myzus persicae* *Aphis gosypii, and* *Toxoptera odinae*	**Non persistent manner**	• Mechanically inoculated groundnut plants showed chlorotic spots and vein clearing on young, systemically infected quadrifoliate leaves 12 to 14 days after inoculation, later leaves showed a severe mosaic. • As infected leaves aged the symptoms become less obvious. • Infected plants were stunted. **(Sreenivasulu, *et al*.,1981)**
Peanut mottle virus disease	Peanut mottle virus(PeMoV)	*Aphis craccivora, Aphis gossypii, Myzus persicae* and *Rhopalosiphum padi*	**Non persistent manner**	• Leaf symptoms on groundnuts include mild dark-green mosaic or mottle; leaflet margins can be crinkled and interveinal tissue depressed. • Occasional leaf necrosis and deformation, chlorotic spots and stunting are also observed. • Infected seeds are often malformed and discoloured **(Abdelsalam *et al*. 1987).**
Peanut yellow spot virus disease	Peanut yellow spot virus (PYSV)	Thrips *Scirtothrips dorsalis*	**Persistent manner**	• Most of the groundnut seedlings which were positive in *Scirtothrips dorsalis*, transmission tests produced characteristic PYSV symptoms within three days. • The symptoms include yellow chlorotic spots and yellow chlorotic patches on partially/fully opened growing buds. • The infected seedlings and leaflets were reduced in size and the seedlings remained stunted for up to 15–20 days. In about 40% of

				positive seedlings, the next emerging leaflets i.e. 1–2 leaflets, showed symptoms. • From the third leaf onwards, the symptoms were masked; the plants produced leaflets similar to healthy plants, but still there was difference in height of the plant. • All the leaflets showing typical chlorotic yellow spots/patches fall-off after the transfer of chlorotic yellow area into necrotic patches. **(Gopal *et al*., 2009)**
Sesame phyllody	*Phytoplasma aurantifolia*	Leaf hopper *Orosius albicinctus*	**Persistent manner**	• Floral parts transformed into green leafy structure – Phylloid structure. • Leaf size is reduced and malformed flowers cluster at the top and the flower become sterile. • Stamens leaf like, anthers green and ovary transformed into shoot like structure. • Excessive axillary shoots are common. • Shortened internodes and gives bushy appearance. **(Raychaudhuri *et al*.,)**
Leaf curl of sesame	Sesame leaf curl virus	White fly *Bemisia tabaci*	Circulative, and persistent	• Yellowing and stunting of the plant may also occur. • The leaves become thickened and brittle, leading to reduced photosynthesis and overall plant vigour. • causes severe leaf curling, reduction in leaf size and stunted growth owing to which the affected plants bear scanty capsules having poor seed setting that results in reduced productivity in most severely affected crops **(Sarwar and Akhtar, 2009)**
Safflower phyllody	*Phytoplasma castaneae*	Leaf hopper *Neoaliturus fenestratus*	**Persistent manner**	• Yellowing leaves • Wilting • Aborted seeds • Floral virescence • Proliferation of auxiliary buds

				• Little leaf symptoms • Extensive fasciation • Formation of bushy growth • Shortened internodes.
Soybean phyllody	*Phytoplasma*	Leaf hopper *Orosius sp.*	**Persistent manner**	• The transformation of the floral calyx and corolla into leaf-like structures. • The plant becomes partially or completely sterile during this process **(Dhopte *et al*., 1997)** and no seeds are formed. • Other symptoms include a reduction in internode length which results in dwarfing, and rosetting and other distortions of the leaves. • If fruits develop, they are malformed and reduced in size with shrivelled and distorted seeds. **(CABI plant wise plus).**
Sunflower mosaic	Sunflower mosaic virus (SuMV)	Aphids *Myzus persicae* And *capitophora elaegni*		• Sunflower mosaic symptoms are most pronounced on leaves younger than 2 months old, appearing as yellow (chlorotic) rings or green to yellow mottling. • Affected plants are stunted and have narrow, light brown streaks on petioles and stems. • Heads of infected plants are malformed and produce shrivelled seed. The disease is rarely an economic problem in the High Plains. **(Schwartz and Gent, 2005).**
Sunflower leaf curl	Sunflower leaf curl virus (SuLCV)	Whitefly *Bemisia tabaci*	**Circulative, non-propagative manner**	• In vegetative stage of the crop, symptoms such as vein clearing, vein thickening, upward curling of leaves, reduction in leaf size, yellow discolouration and enations on the lower surface of leaves and stunted growth are appeared. • Poor development of flower and sick appearance of plants are observed in reproductive stage. • Reduced head diameter, seed weight and oil percentage **(Harshavardhini *et al*, 2023).**



Peanut rosette virus disease



Peanut Stripe virus disease



Peanut Bud necrosis virus disease



Peanut Spotted wilt virus disease



Sesame phyllody disease

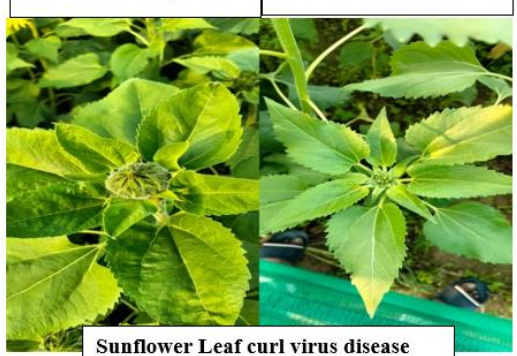


Sesame Leaf curl virus disease



Sunflower mosaic virus disease

Virus affected plant | Healthy plant



Sunflower Leaf curl virus disease

18.

Exercise -14

To study about different diseases of Forest and Plantation crops transmitted by insects

Disease	Causal organism	Vector	Virus vector relationship	Symptoms
Dutch elm disease	Fungus *Ophiostoma ulmi*	Elm bark beetles *Scolytus multistriatus*	***Semi-persistent manner***	• Symptoms first appear in early summer as Clusters of leaves turn yellow then turn brown and fall prematurely. • Affected shoots die back from the tips and twigs turn down to form '**shepherds crooks'**. • Affected twigs have dark streaks in the outer wood beneath the bark, or spots or rings in cross-section. • Because Dutch elm disease is progressive, an affected tree can have a mixture of healthy foliage, yellow or brown foliage, and defoliated shoots, showing infection in different branch systems. • Confirmation of the disease can be obtained by peeling the bark from symptomatic live twigs which show dark brown or purple longitudinal streaks in the outer wood. • Cutting across the twig should reveal a ring of dark brown staining in the outer wood. **(Factsheet)**
Pepper golden mosaic	Pepper golden mosaic virus(PepGMV)	Whiteflies *Bemisia tabaci*	***Persistent manner***	• The typical symptoms induced by PepGMV (Tamaulipas strain) in pepper

				plants are yellow mosaic and wrinkle of the leaf and stunting of the plant. • If a plant is infected at an early stage, only a couple of small, deformed fruits are obtained. (**Carrillo-Tripp *et al*., 2007)**
Leaf and fruit ring spot in coffee	Coffee ringspot virus (CoRSV)	Mite *Brevipalpus phoenicis*	***Persistent propagative manner***	• Coffee plants infected with this virus display conspicuous localized ring spot lesions on both leaves and berries. • The disease is capable of causing significant leaf and fruit drop with accompanying reduced coffee berry yields. **(Subramanya sastry *et al.*, 2020)**
Sandalwood spike	*Sandal spike Phytoplasma*	Leaf hopper *Jassus indicus*	**Persistent manner**	• The new leaves become smaller, narrower or more pointed and fewer in number with each successive year until the new shoots give an appearance of fine spike. • At the advance stage of disease, the inter nodal distance on twigs becomes small, haustorial connection between the host and sandal breaks and the plant dies in about 2 to 3 years. • Sandalwood spike disease is characterized by chlorosis, extreme reduction in leaf size**.** • In advanced stage the entire shoot gives the appearance of spike inflorescence. • Spike plant does not bear flower or fruits. • Redding of leaves and stems. • Stunting of plants and cause phloem necrosis. **(IWST)**
Cassava mosaic	African cassava	White fly	**Persistent**	• Leaves show pale green to

virus disease	mosaic virus(ACMV)	*Bemisia tabaci*	**manner**	yellow patches, giving what is called a 'mosaic' pattern; often, the large yellow areas cover extensive areas of the leaves. • Deformed and distorted leaves and shoots are common and plants are stunted. • There is great variation between leaves, between shoots and between plants of the same variety. • This variation may be due to different strains, the present of complexes of strains, tolerances of the host or differences in environmental conditions, such as soil moisture and temperature. • Some plants do not show symptoms although the virus is present. • In general, the greater the leaf symptoms, the greater the loss in storage root yields. • However, most roots do not show internal symptoms, such as the rots that occur with cassava brown streak disease, but may show rotting caused by soil organisms if plants become severely weakened by ACMV. **(Factsheet,CMV)**
Cassava witches broom	A fastidious xylem limited fungus *Ceratobasidium theobromae*	**Leafhoppers (Cicadellidae), Planthoppers, and Psyllids**	**Persistent manner**	• Symptoms of dwarfism, weak sprouts with short petioles and vascular necrosis were observed (Pardo et al., 2024) • That also causes abnormal shoot growth, stunting, and major yield losses. • Yellowing of leaves, bunching of foliage due to shortening of internodes (the

				distances between leaves)
Sweet potato little leaf	Sweet potato little leaf phytoplasma *Candidatus Phytoplasma aurantifolia*	leafhopper *Orosius lotophagorum ryukyuensis* and *Nesophrosyne ryukyuensis*	**Persistent manner**	• Development of green flowers and loss of normal flower pigments (virescence), development of floral organs into leaf-like structures (phyllody), sterility of flowers, witches' broom, general stunting, dieback, chlorosis, necrosis, little leaves, proliferation of axillary buds and malformation of branches **(Bos, 1957; Lee *et al*., 2000; Streten and Gibb, 2006).**
Vein Mosaic disease of sweet potato	*Sweet potato vein mosaic virus (SPVMV)*	Whitefly *Bemisia tabaci*	Persistent-circulative manner	• The symptoms on sweet potato are stunting, with shortening of the internodes, reduction in leaf size and general chlorosis. • Leaves may be leathery in consistency. • In the varieties with much dissected leaves, segments may be strap-shaped. • Yellow mottling is more obvious in the broad-leaved than in the narrow-leaved varieties.
Leaf curl of sweet potato	Sweet potato leaf curl virus (SPLCV)	Whitefly *Bemisia tabaci*	**Circulative manner**	• The symptoms on sweet potato are pronounced clearing of the veins and slight reduction in leaf size. • It causes minute chlorotic specks between veins mostly on vein- lets. • Subsequent vein clearing is followed by a brilliant mosaic, and plants become stunted and chlorotic **(Loebenstein and Harpaz, 1960).**
Red ring of	Redring	American palm	**Semi persistent**	• The trees show a yellowing and progressive bronzing of

Coconut palms	nematode *Bursaphelenchus cocophilus*	weevil *Rhynchophorus palmarum*	**manner**	the leaves, which advances normally from the older leaves to the younger ones, starting from the tips of the leaflets. • The petioles of the affected leaves generally break a short distance from the base, and several yellowish leaves or semi-necrotic leaves may remain hanging around the trunk. • Parallel to the development of these symptoms, a premature fall of nuts which have not completed their development occurs, plus a necrosis of the inflorescences. • Internally, within the petiole of the affected leaves, and even within some apparently healthy leaves, reddish colorations appear. • In the root area, the bark turns yellow and then reddish. (**Chinchilla,1991)** • When the trunk is cut transversely, a ring of reddish bands can be located near the periphery. In a lengthwise cut, two parallel reddish lines that join at the base of the trunk and end up as discreet stains at the top part may be seen (**Blair, 1970**). • External symptoms of the disease may be indistinguishable from those presented by palms of certain origins attacked by "sudden withering" **(Kastelein, 1987).**
Coconut lethal yellowing	Candidatus Phytoplasma palmae	Plant hopper *Myndus crudus*	**Circulative-propagative manner**	• Lethal yellowing gets its name from the yellowing and drooping of palm fronds. The

				disease characteristically has the following progression. 1. Premature dropping of mature and immature fruits in a process called 'shelling'. Most of the fallen nuts will have a brown or black water-soaked area immediately under the calyx. 2. Flower stalks (inflorescences) begin to blacken. Most male flowers on the blackened inflorescences will die and no fruit will set. 3. Palm fronds start to yellow (or, in the case of some species, turn greyish-brown), beginning with the older, lower fronds and advancing upward through the crown. Fronds that have yellowed will die, turn brown and hang down. 4. The spear leaf collapses and the bud dies. By the time that this happens, the tree is already dead. 5. The entire crown falls from the tree leaving a 'telephone pole' stalk. (**factsheet)**
Coconut root wilt/ Kerala wilt disease.	*Phytoplasma palmea*	Plant hopper *Proutista moesta* and Lacebug	**Persistent manner**	**External symptoms** • The most obvious arid diagnostic symptom of the disease is dying abnormal inward bending of the leaflets termed 'ribbing' or 'flaccidity'. • Foliar yellowing of the outer whorl of leaves and marginal necrosis are the other associated symptoms **(Radha and Lal. 1972).** • In seedlings and juvenile palms yellowing of foliage is virtually absent and

				'flaccidity' is the only symptom evident. • Instances of diseased palms having their outer leaves quite healthy but with yellowing of leaves in some of the inner whorls is also noticed **(Menon, 1938).** • The root system in the early stage of disease is apparently normal arid the percentages of rotten roots are few. • However, with die progress of the disease, extensive rotting of roots is observed **(Menon and Pandalai, 1958).** • The mam roots arid rootlets start drying from tip backwards **(Menon and Nair, 1951).** • The capacity of the palms to regenerate fresh roots is drastically reduced **(Michael, 1964).**
Arecanut yellow leaf Also called 'chandiroga' in kannada 'Kattuveezhcha' And 'Chovaked' in malayalam	Mycoplasma like organisms	Plant hopper *Proutista moesta*	**Persistent manner**	• The main symptom of the disease is yellowing of leaves. • The yellowing starts from the tips of the leaflets of the outer leaves gradually extending along the margin to the middle of the lamina. • The affected leaves often develop necrosis from their tips. • In advanced stages, the leaves become smaller, stiff and pointed. • The crown gets reduced and the palm is stunted giving very few or no nuts at all. • Root tips become dark and they gradually rot. Kernel of affected nuts shows discolouration and later turns

				blackish. • Such nuts are unfit for chewing and fetch only a lower price. **(CPCRI, Kerala)**
Pine wilt disease	Pinewood Nematode *Bursaphelenchus xylophilus*	Cerambycid beetles *Monochamus carolinensis* *M. alternatus*	**Persistent manner**	• Pine wilt disease (PWD), the disease of pines, is so nasty that after getting the disease the infected tree becomes dead within a few weeks to a few months. • The usual symptom is needles' discolouration. • Their colour first changes to greyish green and finally it turns out to be totally brown. • Infected pine trees cease oleoresin after succumbing to the disease. **(Yano,1913)**
Marigold **or** Tagetus phyllody	*Candidatus Phytoplasma aurantifolia*	Leaf hopper *Orosius albicinctus*	**Propagative manner**	• Characteristic symptoms of the PMP disease were leaf size reduction, yellowing, phyllody, virescence, proliferation and sterility in the flower, proliferation of axillary buds along the stem, Witches' broom and stunting. **(Esmailzadeh-Hosseini *et al*., 2011).**
Rose rosette disease (RRD)	Rose rosette virus(RRV)	Eriophyid mite *Phyllocoptes fructiphilus*	**Semi-persistent or persistent manner**	• Generally symptoms first appear on leaves, before emerging on stems and branches. • Leaves redden and become distorted, whilst shoots elongate and redden. • Witches' brooms and excessive thorniness are characteristic of RRV infection, and these particular symptoms are more easily distinguishable in winter when stems are not masked by dense, healthy foliage.

				• During the later stages of infection, reduced flowering and flower malformations are common. • Diseased plants exhibit a gradual decline and die within 1-5 years, usually as a result of enhanced susceptibility to frosts. • Rose rosette virus symptom progression is quicker in smaller, younger plants with infected seedlings rarely surviving after one year. **(Plant Pest Factsheet)**
Yellow mosaic of rose	Rose yellow mosaic virus (RYMV)	Whitefly *Bemisia tabaci*		• Characterized by the appearance of yellow coloured bands adjacent to veins. • In severe cases these bands spread and cause clearing of the veins and veinlet's. • As the disease progresses, veins and veinlet's become more yellow and exhibit a yellow net pattern. • The virus is transmissible by *B. tabaci* and by budding**. (Bhargava and Joshi, 1962)**
Rose mosaic	Prunus Necrotic Ringspot Virus (PNRSV) And Apple Mosaic Virus (ApMV).	Transmitted through vegetative propagation especially by grafting or budding	--	• The symptoms are highly variable, depending on the variety, the virus and the environment. Some of the more common symptoms include; chlorotic bands or ring spots, wavy lines, yellow vein banding, oak-leaf pattern, and general mosaic (splotches of yellow andngreen on leaves). • Color-breaking (mottled flower colour) has also been reported in some cultivars. Symptom development on

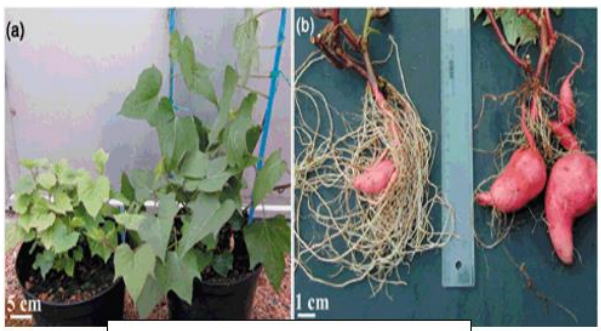
				only a portion of a plant is common. • Some infected plants never express symptoms. • Symptoms usually appear in the spring and remain throughout the growing season. **(Goldberg, 2006)**
Rose leaf curl	Rose leaf curl virus (RoLCuV)	Whitefly *Bemisia tabaci*	**Circulative and persistent manner**	• Dwarfing, leaf distortion and leaf curl.
Chlorotic ring spot of Jasmine	Jasmine chlorotic spot virus (JCSV) and Jasmine virus T	Whitefly *Bemisia tabaci*	**Circulative manner**	• The infected plants show typical mosaic symptoms consisting of yellow chlorotic spots or areas of varying size and shape, intermingled with the green colour of the leaves. • Frequently yellow coloured rings with green centres appear on some of the leaves along with the mosaic pattern. • The rings generally measured 2mm to 6mm in diameter. • These rings are not delimited by veins. • These ring spots were more abundantly seen soon after pruning when the plants put forth new foliage luxuriantly. **(Ramakrishna, 2000)**



Cassava mosaic virus disease



Cassava witches broom disease



Sweet potato little leaf disease



Sweet potato Leaf curl virus disease



Red ring of coconut



Coconut lethal yellowing disease



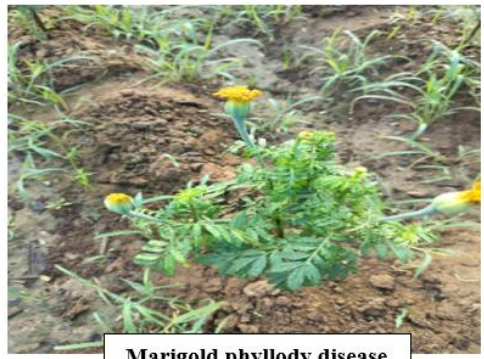
Coconut root wilt



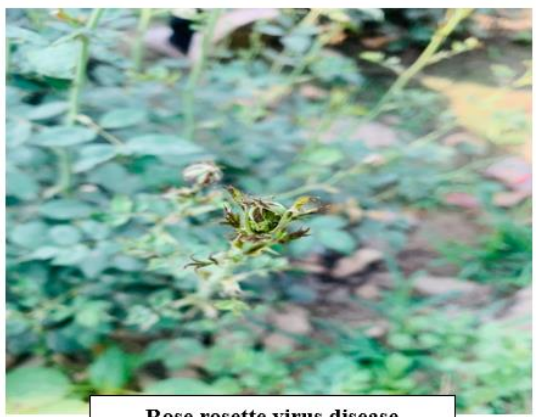
Arecanut yellow leaf disease



Pine wilt disease



Marigold phyllody disease



Rose rosette virus disease



Yellow mosaic virus disease of Rose



Rose mosaic virus disease



Rose Leaf curl virus disease



Chlorotic ring spot of Jasmine

Exercise -15

To study about different diseases of Medicinal crops transmitted by insects

Disease	Causal organism	Vector	Virus vector relationship	Symptoms
Acalypha witches broom	Phytoplasma	**Leaf hopper**	**Persistent manner**	• The main symptoms observed in the affected plants include - shortening of internodes, stunted growth, leaves- small in size, Pale yellow coloured, more in numbers and arranged in condensed form. • Excessive proliferation of shoots resulting in a witches' broom; phyllody, Virescence, sterile flowers, necrosis of the phloem tissues, die back of the branches and the general decline and Death of the plants. **(Singh and Gupta, 2011)**
Cannabis phyllody	Phytoplasma	American grapevine leafhopper *Scaphoideus titanus*	**Persistent manner**	• Shortening of internodes, stunted growth, leaves- small in size, pale yellow coloured, more in numbers and arranged in condensed form. • Other symptoms include witches broom; phyllody, sterile flowers, necrosis of the phloem tissues, die back of the branches. **(Singh and Gupta, 2011)**
Periwinkle virescence	***Mycoplasma-like organisms***	Beet leaf hopper *Neoaliturus tenellus*	**Persistent manner**	• Periwinkle plants with yellowing, virescence and witches'- broom symptoms **(Ayman *et al.*, 2010)**
Tomato spotted wilt of stevia	*Tomato spotted wilt virus*	Thrips *Frankliniella occidentalis*	Persistent, propagative manner.	• Diseased *Stevia rebaudiana* plants expressed chlorotic and necrotic rings and line patterns on systemically infected leaves and occasionally a general chlorosis or

				dwarfing of the plant. (**Chatzivassiliou *et al*., 2007)** • Distortion and chlorosis of leaves and progressed to include necrotic leaf lesions, stem lesions, severe dieback, and plant death.
Witches broom of *withania* / Goat weed witches' broom	*Candidatus Phytoplasma aurantifolia*	Leafhoppers	**Persistent manner**	• Typical symptoms of the disease consisted of little leaf, shortening of internodes, excessive branching giving witches-broom appearance and premature drying and death of infected twigs and leaves. • Ultrathin sections of infected leaf tissue showed pleomorphic bodies (measuring 250–550 nm) in sieve tubes of phloem. **(Zaim and Samad, 1995)**
Yellow vein mosaic of Ageratum	Ageratum yellow vein virus DNA A and DNA β	Whitefly *Bemisia tabaci*	**Circulative manner**	• The yellow veins of top leaves of infected plants appear as yellow bands narrowing and growing less yellow towards the leaf base. • On the under surface, the vein banding is less conspicuous, but the veins are yellow and stand out prominently owing to the interveinal areas being concave. • Infected plants are stunted (**Gadd and Loos, 1942).**
Yellow vein mosaic of Blumea		Whitefly *Bemisia tabaci*	**Circulative**	• The disease is characterized by pronounced vein clearing in the leaves. • In severely affected leaves, the yellowing diffuses into surrounding interveinal areas, thus leading to mottling. • Veins on the lower side are sometimes slightly thickened. • The virus is transmitted by *Bemisia tabaci*. Cross inoculation with the virus causing yellow vein mosaic on *Hibiscus esculentus* and *Ageratum conyzoides* in the vicinity failed. **(Wilson and Potty, 1972)**

Yellow vein mosaic of *Legendra mollissima*		Whitefly *Bemisia tabaci*	**Circulative**	• The virus produces typical yellow vein symptoms on leaf lamina. • The virus is transmissible by grafting and by *Bemisia tabaci.* • The virus could not be transmitted to tobacco, tomato, bhendi, *Ageratum conyzoides* and *Malvastrum coromandelianum,* thus suggesting that the virus is different from other yellow vein mosaic diseases. **(Varma, 1962)**
Leaf curl of *Hibiscus rosa sinensis*	Hibiscus yellow vein leaf curl virus (HYVLCV)	Whitefly *Bemisia tabaci*	**Circulative manner**	• The disease is characterized by curling of affected leaves to varying degrees and the formation of enations on their under surfaces**. (Varma, 1962)**
Yellow vein mosaic of Hibiscus rosa-sinensis	Caused by complex of viruses including Mesta yellow vein mosaic virus (MYVMV)	Whitefly *Bemisia tabaci*	Circulative, non-propagative manner	• The Hibiscus rosa-sinensis mosaic virus causes a range of symptoms including mosaic patterns on leaves, leaf distortion, and stunted plant growth. • Infected plants may exhibit yellowing or chlorosis of the leaves, and in severe cases, the virus can lead to a significant reduction in plant vigour and flower production.
Yellow vein mosaic of Hibiscus cannabinus (Kenaf/Mesta)	Mesta yellow vein mosaic virus(MeYVMV)	Whitefly *Bemisia tabaci*	Circulative, semi persistent manner	• Progressing to a conspicuous yellow network of veins. The plants became stunted. • In symptomatic plants, the fibre yield is greatly reduced.
Yellow vein mosaic of *Salvia splendens*	Clerodendron golden mosaic china virus (CIGMCNV)	Whitefly *Bemisia tabaci*	Circulative manner	• It produces vein clearing, vein necrosis, and dwarfing and reduced flower production. • It was easily transmitted by grafting and *Bemisia tabaci*, but not by sap inoculation **(Varma, 1974).** • It also causes yellow mosaic and mild leaf distortion.
Leaf curl of balsam	Balsam leaf curl virus	Whitefly *Bemisia*	Persistent and	• Infected plants showed thickening of the lower surface of

		tabaci	circulative manner	the veinlet's, stunting and leaf distortion. • None of affected plants flowered **(Verma and Singh, 1973)**
Tomato spotted wilt of basil	*Tomato spotted wilt virus* (TSWV)	Thrips *Thrips tabaci, Frankliniella occidentalis*	**Persistent and propagative manner**	• Symptoms include ring spots, leaf distortion and severe mosaic.
Leaf curl of Basil	Basil leaf curl virus	White fly *Bemisia tabaci*	**Persistant, circulative and Non-propagative**	• Severe distortion, upward or downward curling, and yellowing of leaves, making them leathery, thick and brittle. • Infected plants show stunted growth, shortend internodes, and reduced leaf size and resulting in no flower or fruit production.



Periwinkle Virescence



Yellow vein mosaic virus disease of Ageratum



Leaf curl of Hibiscus Rosa sinensis



Yellow vein mosaic virus disease of Hibiscis Rosa sinensis



Yellow vein mosaic virus disease of Hibiscis cannabinus



Basil leaf curl virus disease

Exercise-16

To estimate vector transmission efficiency

Vector transmission efficiency of plant viruses refers to how effectively a vector, such as an insect, can acquire a virus from an infected plant and then transmit it to a healthy plant, leading to infection.

Experimental calculation of Transmission efficiency:

The basic process includes

- **Virus-free vectors:** vectors(e g : insects) are initially virus free before being exposed to infected plants to acquire the virus
- **Source Plant Exposure:** Virus-free vectors are allowed to feed on infected source plants for varying durations (acquisition access period, AAP). The efficiency is the probability of successful virus acquisition by the vector over time.
- After incubation period, testing the recipient plants for infection. There are currently two main methods for virus diagnosis
  - **ELISA (Enzyme linked immune sorbent assay):** A widely used technique to detect the presence of viral antigens in plant tissues or vectors, allowing for high-throughput analysis.
  - **RT-PCR or PCR:** Used to amplify and detect viral nucleic acids within the vector or plant.
- **Target Plant Exposure:** Virus-carrying vectors are exposed to healthy plants for different periods (inoculation access period, IAP). Efficiency is determined by the number of plants infected after these periods.
- **Calculating Efficiency:** the transmission efficiency(%) is calculated as

$$Transmission\ efficiency\% = \frac{Number\ of\ \ plants\ \ infected\ with\ virus}{Total\ number\ of\ plants\ exposed\ to\ vectors} \times 100$$

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