Vector-borne Viral Diseases of Cucurbitaceous Crops and their Integrated Management

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Cucurbits are one of the most economically significant and extensively grown crops in subtropical areas of the world. They play an important role in human nutrition and rich in vitamins, minerals, antioxidants, and dietary fibre. The production and productivity of these crops are being declining due to number of biotic and abiotic factors, among all currently viral diseases are causing huge economic losses. Till date, more than 70 viruses belonging to *Begomovirus*, *Potyvirus*, *Cucumovirus*, *Polerovirus* and *Tospovirus* groups reported to cause the disease in cucurbits and are rapidly spreads by vectors such as aphids, thrips, whiteflies, beetles, fungi and nematodes. Stunted growth, Mottling and mosaic symptoms on leaves, leaf deformation, and undersized, malformed fruits are the signs of infected plants, these infections cause 100% economic loss. Managing diseases in cucurbits is very difficult once a plant is infected, so prevention is the best option to manage this disease. An integrated approach of combining cultural, mechanical, chemical, and biological approaches at timely interval is the key for the effective and successful management of these viruses and vectors. Integration of these strategies is crucial for minimizing losses and ensuring stable cucurbit production under changing climatic scenarios.

Keywords: *Cucurbitaceous crops, Begomovirus, Mosaic, aphids, Integrated management*

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Publisher: Cornous Publications LLP., Puducherry, India.
Integrated Crop Pest Management Using Innovative Approaches
Editors: Dr. Srinivasa N, Dr. Ramesh K B, Mr. Varun Arya, Dr. Twinkle
ISBN: 978-81-993853-5-1
DOI: https://doi.org/10.37446/edibook252025/180-190

Introduction

Cucurbitaceous crops are highly valued because of their rich content of essential vitamins, minerals, antioxidants, and dietary fibres. Globally, cucurbit production is estimated to be about 151 million tonnes, and in India it is approximately 6.5 million tonnes, this represents a major portion of the total production in South Asia (Rolnik & Olas, 2020). In India, cucurbit occupy 4.29 mha and produce 5.6 % of the total vegetable production with 10.5 t/ha productivity. A wide variety of cucurbit species are grown in the different agro-climatic areas of India. Important crops include pumpkin (*Cucurbita maxima*), snake gourd

(*Trichosanthes cucumerina*), bitter gourd (*Momordica charantia*), ash gourd (*Benincasa hispida*), ridge gourd (*Luffa acutangula*), bottle gourd (*Lagenaria siceraria*), cucumber (*Cucumis sativus*), gherkin (*Cucumis anguria*), ivy gourd (*Coccinia grandis*), muskmelon (*Cucumis melo*), watermelon (*Citrullus lanatus*), chayote (*Sechium edule*) and sponge gourd (*Luffa aegyptiaca*) (Patel et al., 2018).

Cucurbits occupy a substantial area under cultivation and play an important role in vegetable production as well as in supporting farmers' livelihoods. However, their productivity is affected by several biotic stresses, among which viral diseases are particularly serious. These diseases reduce plant growth and yield, and also affect fruit quality by causing symptoms such as mottling, deformation and discoloration, making the produce unmarketable.

All over the world, cucurbit crops have been recorded to be affected by at least 70 viruses. These belong to different genera, including *Begomovirus*, *Potyvirus*, *Cucumovirus*, *Tobamovirus*, *Tymovirus*, *Nepovirus*, and *Polerovirus*. These viruses include both RNA and DNA types and are transmitted through various means, posing a continuous challenge to cucurbit cultivation (Abdalla et al., 2012; Dreher et al., 2012; Sobh et al., 2012; Mansilla et al., 2013; Lecoq & Katis, 2014; Nagendran et al., 2015a and Nagendran et al., 2015b). Unlike fungal and bacterial pathogens, viruses cannot be managed effectively once infection spreads. Since the vectors spread viruses rapidly within and between crop fields, leading to severe epidemics. Yield losses due to viral infections in cucurbits may range from 30% to 100% depending on crop stage, virus strain, and environmental conditions. With the increasing movement of planting materials, climate change, and expansion of vector populations, the incidence and severity of viral diseases in cucurbits are increasing worldwide.

Therefore, effective management of vector-borne viral diseases requires a holistic integrated approach, combining cultural practices, vector management, host resistance and use of healthy planting materials. This chapter discusses the important vector-borne viruses affecting cucurbitaceous vegetables, their symptoms, vectors, epidemiology and integrated management strategies.

Important Vector-Borne Viral Diseases of Cucurbit Crops

Plant viruses are obligate parasites that typically rely on vectors for their survival and transmission between susceptible hosts (Hull, 2002). Developing efficient and focused control techniques requires an understanding of the mechanisms by which a virus spreads within a field. Accordingly, the major cucurbit viruses are listed below based on their associated vectors.

Aphid borne viruses

Cucumber Mosaic Virus (CMV)

Among the top ten plant viruses worldwide, CMV is a very damaging cucurbit virus belonging to the genus *Cucumovirus* and family *Bromoviridae*. Because of its widespread distribution and several modes of transmission, it presents a serious threat to cucurbit production. The tripartite genome of CMV, a positive-sense single-stranded RNA (ssRNA) virus, is contained in isometric particles with a diameter of 30 nm. RNA 1, RNA 2, and RNA 3 are the three genetic RNAs found in each particle. RNA 1 and RNA 2 are enclosed independently, whereas RNA 3 and its subgenomic RNA-4 are confined together. These RNA segments encode a number of vital viral proteins, including 1a (replicase), 2a, 2b, 3a (movement protein), and 3b (capsid protein). Additionally, CMV is known to support satellite RNA (satRNA) known as RNA 5, a that helps the virus and its aphid vectors spread (ICTV, 2024). More than 800 species from 70 botanical groups are infected by this virus, which has wide host range. The virus is non-persistently disseminated in cucurbits by over 70 different species of aphids infecting crops like cucumber, muskmelon, watermelon, pumpkin, bottle gourd, and bitter gourd. The virus causes symptoms like mosaic, mottling, leaf distortion, stunting, and malformed fruits, resulting in yield losses of 20–80%.

Zucchini Yellow Mosaic Virus (ZYMV)

It belonging to genus *Potyvirus* in the family *Potyviridae* problematic in tropical and subtropical regions. It Virus particles are flexuous are between 680 and 730 nm length. This virus spreads in non-persistent manner and through seeds across a number of aphid species. Aphid vectors are involved in the virus's transmission from cucurbit crops to weeds and within farmed areas (Lecoq et al., 2009). The common symptoms in infected cucurbit plants exhibits the symptoms of mosaic, leaf deformation, blisters, leaf chlorosis, and overall stunting. Fruits with severe systemic infections develop surface discoloration and deformities that make them unmarketable. ZYMV can cause mild to severe yield losses and reported to cause up to 80% economic loss (Ahsan et al., 2023).

Watermelon Mosaic Virus

One of the first viruses known to cause mosaic disease in cucurbits, it belonged to the genus *Potyvirus*. Aphids, particularly *A. gossypii*, transmit it in a non-persistent way. It results in rapid and severe epidemics in crops such as watermelon, muskmelon, pumpkin, squash, and cucumber. Infected plants exhibit mosaic and mottling on leaves, along with blistering, yellowing, and significant stunting. Fruits often become distorted with wart-like protrusions, making them unmarketable (Romay et al., 2013).

Papaya Ringspot Virus-Watermelon Strain (PRSV-W)

It belongs to the genus *Potyvirus* in the family *Potyviridae* and is a serious viral disease that affects mainly papaya and cucurbits. It was originally known as Watermelon mosaic virus-1 (WMV-1). The virus consists of filamentous, flexible particles about 12 nm in diameter and 760-800 nm long (Herold & Weibel, 1962). The viral genome encodes a single-stranded RNA of approximately 10 kb in size, which is translated into a large polyprotein, which is divided into several proteins, including a coat protein of about 36 kDa (Fernandez-Rodriguez et al., 2008). While the amino acid sequence of the N-terminal region is variable, the central hydrophobic region is well conserved among isolates. It contains two distinct strains of the virus: PRSV-P and PRSV-W. While its PRSV-W strain is limited to cucurbits, the PRSV-P strain can affect both papaya and cucurbits and produces serious disease in papaya. The virus causes severe mosaic, leaf constriction, and, in later stages, the distinctive shoestring appearance in cucurbits; the fruits are sometimes malformed and have green spots. More than 20 species of aphids, including *M. persicae* and *A. gossypii*, serve as vectors for the virus, which is mainly spread by them in a non-persistent way.

Cucurbit Aphid-Borne Yellows Virus (CABYV)

This virus belongs to the *Polerovirus* genus. The virus was initially reported in France (Lecoq et al., 1992). It belongs within the family Solemoviridae, molecularly, CABYV is separated into two primary groups: Asian isolates and those from Europe, Africa, and the America. It has been linked to a severe "Namamarako" bitter gourd condition in the Philippines, which is noticeable by distorted leaves, banding on veins and exhibits interveinal chlorosis. In India, it was initially identified in teasel and bitter gourds in Karnataka. More recently, it has been found in crops such as ash, snake, round, sponge, bottle and gourds.

Infected plants have interveinal chlorosis, yellowing of leaves, thickening, brittleness along with leaf drop resulting in lowered yield, though the quality of fruit is not greatly affected, mainly due to drop of flowers and fruits. Aphids, primarily *A. gossypii*, *M. persicae*, and *Macrosiphum euphorbiae*, are responsible for the circulative non-propagative transmission of this virus, which is restricted to phloem cells only. The virus is neither seed nor mechanically transmitted and weeds are important reservoirs (Rabadan et al., 2025).

Whitefly Borne Viruses

Tomato Leaf Curl New Delhi Virus (ToLCNDV)

In tropical and subtropical countries, ToLCNDV has evolved into a serious threat to the cultivation of vegetables. It is a bipartite begomovirus belongs to family *Geminiviridae* with a genome made up of two circular single-stranded DNA molecules, DNA-A and DNA-B (Srivastava et al., 1995). Moreover, the virus often occurs with betasatellites that are essential for the development of severe symptoms, presumably by suppressing the plant's defense system (Srivastava et al., 1995). Virus was first recorded in tomato from northern India in 1995. Since then, it spread to a wide range of hosts and geographical areas. Now it a causing serious problem in cucurbitaceous crops, namely zucchini, cucumber, melon, watermelon, and pumpkin (Siskos et al., 2022; Venkataravanappa et al., 2020). The symptoms include leaf curling, yellowing, and vein swelling, as well as reduced fruit size, roughness, cracking, and poor growth. It is transmitted primarily by whiteflies (*B. tabaci*) and infestations are spreading quickly. This is partly due to the wide adaptability of the "B-type" whitefly biotype coming from the Mediterranean region. Whiteflies carrying ToLCNDV can transmit it for several days or for the duration of their life after feeding on an infected plant.

Watermelon Chlorotic Stunt Virus (WmCSV)

It is a bipartite begomovirus belonging to the *Geminiviridae* and its genome organization is similar to Squash leaf curl virus (SLCV). This virus was first reported in Yemen (1986) in the infected watermelon plants. The primary hosts are watermelon and other melon plants, which are separated from wild cucurbits (*Citrullus colocynthis* and *Cucumis melo* var. *agrestis*) and snake cucumber (*C. moschata*). Infected plants clearly show typical symptoms of chlorotic mottling, yellowing veins, stunting of younger leaf growing and yields will drastically reduce (Mahanta & Dhakal, 2026). WmCSV transmit by the whitefly (*B. Tabaci*) by circulative and persistent mode.

Squash Leaf Curl Virus (SLCV)

It is a bipartite Begomovirus and classified as part of the *Geminiviridae* family, is distinguished by geminate particles that are roughly 22 × 38 nm in size. Both the complementary sense (AC1-4, BC1) and the sense of virion (AV1, BV1) are encoded by the genome. *C. Melo*, *C. Sativus*, *C. Lanatus*, *Cucurbita pepo*, *C. Maxima*, and *C. Moschata* are among the host plants (Ali-Shtayeh et al., 2014). Stunting, leaf curling, the emergence of chlorosis, and mosaic symptoms (especially serious in melon and squash) are the characteristics of infected plants. The whitefly vector, *B. tabaci*, is the persistent transmitter of this virus.

Cucurbit Yellow Stunting Disorder Virus (CYSDV)

The infected plants show the symptoms of yellowing in older leaves, interveinal chlorosis, stunted growth, and reduced yield, particularly in areas with high whitefly populations. Overall, insect vectors such as aphids (notably *A. gossypii* and *M. persicae*) and whiteflies (*B. tabaci*) play a major role in the rapid spread of cucurbit viruses; other insects like thrips and leafhoppers may occasionally act as minor vectors (Krishnan et al., 2022).

Cucumber Vein Yellowing Virus (CVYV)

This virus is a member of the *Potyviridae* family and genus *Ipomovirus* and has a single filamentous RNA genome of roughly 9.7 kb. It was first identified in Israel and damages a variety of cucurbit crops, such as Pumpkin, Muskmelon, Cucumber, Watermelon etc., in addition to affecting weed hosts such Field bindweed, Squirting cucumber, and Cheeseweed. The plants show the typical symptoms of vein yellowing, reduced plant growth, and finally results in the significant yield losses. Infected cucumber fruits show pale green mosaic, watermelon leaves may develop cracking, and melon plants exhibit thinning, necrosis, and stunted growth. The virus is transmitted by mechanically and by the vector whitefly (*B. tabaci*) in a semi-persistent manner (Mansour & Al-Musa, 1993).

Thrips Borne Viruses
Watermelon Bud Necrosis Orthotospovirus (WBNV)

WBNV is a common virus in the Indian subcontinent and belongs to the genus *Orthotospovirus* (Family: *Tospoviridae*). This causes a yield loss of up to 100% and primarily affects cucurbits, such as watermelon, muskmelon, and bottle gourd. It is made up of quasi-spherical, enclosed particles (80-110 nm) that are encased in an envelope of lipids with glycoprotein (Gn/Gc) spikes and contain genomic RNA associated with a nucleoprotein and viral polymerase. Mottling, yellowing, necrosis streaks on vines, reduced internodes, extensive stunting, stem plus bud necrosis, and dieback are symptoms of infections. Melon thrips (*T. palmi*) transmits this virus in a persistent-propagative way.

Beetle Borne Viruses
Squash Mosaic Virus (SqMV)

It belongs to a genus *Comovirus* and family *Secoviridae*. The genome consists of two separately encapsidated positive- ssRNA with a 5'end-bound polypeptide (VPg) and a 3' end poly(A) tail (Sanfacon et al., 2012). The virus is transmitted by beetles and can retain viral particles for days to weeks. This virus is also reported seed-borne nature in melon and squash with a transmission rate of nearly 10% (Alvarez and Campbell, 1978). The infected plants exhibit the symptoms of vein banding, mosaic and deformation of leaves (Lecoq et al., 2016).

Chayote Mosaic Virus (ChMV)

It is a member of the family *Tymoviridae* and genus *Tymovirus*. It has a genome of around 6.3 kb and constitutes a linear, positive-sense ssRNA. The virus is mechanically transmitted and also transmitted by beetles (*Chrysomelidae* and *Curculionidae*) in a semi persistent manner. The host range is limited to cucurbit species; the infected plants exhibit the symptoms of mosaic and leaf corrugation. Symptomless infections were recorded in different families such as *Solanaceae* and *Amaranthaceae* (Bernal et al., 2000).

Nematode Borne Viruses
Tobacco Ringspot Virus (TRSV)

Melons and cucumbers are commonly affected by this virus. The infected plants exhibit the symptoms of mosaic, chlorotic ringspots, and mottling on leaves, stunted and deformed fruits are observed (Abdalla et al., 2012). It is a member of the *Nepovirus* family and is primarily dispersed by the dagger nematode called *Xiphinema americanum*. Furthermore, seeds, mites, and aphids are capable of spreading the virus.

Tomato Ringspot Virus (TmRSV)

It causes severe damage to summer and winter squash, although it produces only mild symptoms in other cultivated cucurbits. Similar to TRSV, TmRSV is transmitted by nematodes. It survives in various weed species without showing visible symptoms in the cold or winter seasons.

Fungus Borne Viruses
Melon Necrotic Spot Virus (MNSV)

This virus is a member of the *Tombusviridae* family and the genus *Carmovirus*. It is a single-stranded, linear, positive-sense RNA that weighs approximately 4 Kb. The vast majority of Carmovirus species are easily transmitted mechanically and are soil-borne. *Olpidium bornovanus* is a fungus that spreads this virus. Due to the association among melon vine decline and *O. bornovanus* and viral infection, serious diseases and losses occurred in Guatemala. MNSV has been associated to stem necrosis, necrotic leaf patches, and plant wilting in commercial melon crops in Panama. Additionally, a vector-assisted seed transmission mechanism has been witnessed for this virus in melon (Campbell et al., 1996).

Squash Necrosis Virus (SqNV)

Squash necrosis virus (SqNV), a species of Carmovirus, has been reported from Brazil and the island of Martinique. Squash infections result in systemic necrotic signs, especially on the leaves and stems. The motile zoospores of the chytrid fungus *Olpidium bornovanus* represent the main mode of transmission for the soil-borne virus. Furthermore, grafting, handling sick plants, and utilizing contaminated equipment and tools may all result in mechanical transmission. The symptoms include noticeable necrotic lesions, dark streaks along the stems, and dark necrotic patches or blotches on the leaves. Fruit quality and production might be affected as a result of infected plants' reduced growth, diminished vigor, as well as poor fruit development.

Reasons for the Emergence of Viruses in Cucurbits

The emergence of new viruses in cucurbit crops is driven by a combination of biological, environmental and agricultural factors. RNA viruses, in particular, have high mutation rates and can undergo recombination, resulting in the formation of new, more virulent strains. Changes in vector populations such as aphids and whiteflies or behaviour, often driven by climate variability, can increase virus spread within and between fields. Environmental factors, in particular high temperatures and irregular rainfall events, further promote virus infection and vector proliferation. Human activities such as dissemination of infected seeds and seedlings, intensive monoculture practices and poor pest management helps in the emergence of new viruses. Weeds and wild cucurbit species also serve as alternate hosts for viruses to survive between cropping seasons. Viruses can overcome host resistance over time, leading to a re-emergence of diseases in previously resistant cultivars.

Integrated Management of Vectors and Viruses

The broad host range of both insect vectors and viruses, the quick development of resistance in vectors, the rapid evolution of viruses because of mutation and recombination, and a lack of resistant sources contribute to making it difficult to develop effective management strategies for viral diseases spread through insects. In order to successfully control viral infections in vegetable crops and reduce the environmental pesticides load, integrated management approaches that encompass host plant resistance, induced resistance, biological, cultural, and chemical treatments should be implemented.

Cultural Practices

- Use of certified virus-free seeds and healthy seedlings. Nursery raising under insect-proof net houses (25-40 mesh size) significantly reduces early-stage infection.
- Regular field scouting is essential to identify early symptoms such as mosaic, leaf distortion, vein clearing, and stunted growth. Infected plants should be removed and destroyed immediately to eliminate virus sources.
- A buffer zone free of weeds should be maintained in and around field at least 25m to reduce the viral inoculum. Because weeds like *Parthenium hysterophorus* and *Euphorbia spp.* harbour aphids and viruses affecting cucurbits.
- Rotating cucurbits with non-host crops such as cereals (maize, wheat) or legumes helps break the disease cycle and reduces vector population build-up. For example, rotation of cucumber → maize → cowpea reduces whitefly population and virus incidence.
- Planting barrier crops like maize or sorghum around cucurbit fields helps reduce vector entry by acting as a physical and visual barrier. Two to three rows of maize around watermelon fields significantly reduce aphid-mediated virus transmission.
- Silver or aluminium-coated reflective mulches repel aphids and whiteflies by disorienting them, thereby reducing virus transmission during early crop stages.
- Regular monitoring using yellow sticky traps for aphids and whiteflies and blue traps for thrips helps in early detection and timely management. Usually 10–12 sticky traps per hectare required for managing the vector population.

Use of Botanicals

Products based on neem like Azadirachtin, neem oil and neem seed kernel extract (NSKE) 5% are widely used in the infected fields for their antifeedant, repellent and growth regulating properties. Neem oil @ 3 ml/L or NSKE 5% or Azadirachtin 1500-3000 ppm @ 2-3 ml/L can effectively control aphids, white flies and thrips. Karanj oil (*Pongamia pinnata*) is a contact insecticide and repellent for sucking pests. The garlic-chilli extract acts as a natural repellent and mild insecticide, and decreases the initial colonization by vectors. Tobacco (nicotine-based) decoction is effective against aphids and whiteflies, but use with care as it is toxic. Pyrethrum extract of *Chrysanthemum* spp. is a contact insecticide for a wide range of insect vectors and has a rapid action.

Biological Control

- For the biological control of insect vectors, entomopathogenic fungi such as *Beauveria bassiana*, *Lecanicillium lecanii* (formerly known as *Verticillium lecanii*), and *Metarhizium anisopliae* can be given at a rate of 1 L/ha. These fungi can help reduce vector populations in field conditions and are effective against major virus-transmitting pests such as thrips, whiteflies, and leafhoppers.
- Plants' natural protection against insect pests and related diseases can be strengthened by the beneficial bacterium *Pseudomonas fluorescens*, which can cause systemic resistance. It can be applied using a variety of techniques, such as foliar spray at 300 CFU/mL, soil drenching with 25 mL of a 300 CFU/mL solution per plant, seed treatment at 300 CFU/mL, or seedling immersion in a 300 CFU/mL suspension for two hours.
- The nematode, Steinernema feltiae parasitises thrips and may be used for the successful management.
- Ladybird beetles (*Coccinella septempunctata*) feed on aphids among predators, and the larvae of green lacewings (*Chrysoperla zastrowi sillemi*) feed on aphids, whiteflies and thrips.
- Predatory anthocorid bugs, including *Orius maxidentex* and *Orius tantillus*, actively prey on thrips and are therefore useful in reducing thrips populations. Predatory mites such as *Amblyseius* spp. and *Stratiolaelaps scimitus* may also be released at approximately 50–100 individuals/m^2, particularly under protected cultivation where thrips infestations are severe. Collectively, these biological control agents can be integrated into an IPM programme to suppress insect vectors and reduce the risk of virus transmission.

Chemical Control

Reducing viral transmission and associated yield losses requires proper handling of insect vectors. By reducing vector populations, systemic insecticides such as Acetamiprid (100 g/ha), Dimethoate (2 ml/L), Imidacloprid (0.5–0.75 ml/L), Thiamethoxam (500 g/ha), Fipronil (1.5 ml/L), and spiromesifen (1 ml/L) etc. could reduce the effect and transmission of viral infections. Furthermore, resistance-inducing substances like salicylic acid and Acibenzolar-S-methyl have been shown to limit the development of symptoms and minimize viral accumulation, which correlates enhance disease control. Instead of continuously depending on a single pesticide group, products with various modes of action should be carefully rotated to postpone the emergence of insecticide resistance.

Conclusion

Vector-borne viral diseases are a major problem to cucurbit production throughout the world. Vectors such as aphids and whiteflies are the primary vectors responsible for transmission and spread of the vectors. As viral infections are incurable once established, so emphasis must be to prevent the occurrence and spread. The best sustainable way to manage these viral diseases is through an integrated approach which includes the use of resistant host plants, cultural practices, biological control methods, and the judicious application of pesticides. Recent progress in molecular diagnostics, genomics and biotechnology has created new possibilities for managing the diseases. Techniques such as PCR-based detection, next-generation sequencing, and genome editing technologies including CRISPR/Cas enable precise identification of the viruses and the development of resistant varieties. Climate change is expected to change vector population patterns and in future it may lead to an increase in the occurrence and dissemination of viral diseases. Therefore, it is necessary to focus our research into virus epidemiology, vector ecology and the breeding of resistance.

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