MINI REVIEW

Chili Leaf Curl Virus: A Common Threat in Chili *(Capsicum annum var. annum)* Cultivation

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Abstract

Chili (*Capsicum annuum* L.) is a widely cultivated vegetable crop that is susceptible to around 45 viruses. Among these, 24 are known to occur naturally, while the remaining can infect plants only through artificial inoculation. Out of the 24 naturally occurring viruses in chili, approximately 11 have been reported in India. The most serious of these is the chili leaf curl virus (LCV), which can lead to yield losses of up to 100% in severe cases.

This disease is caused by begomovirus, which can be identified by distinct symptoms such as yellowing of veins, mosaic-like yellow patterns, and curling of leaves. Efforts to control chili LCV through cultural practices or chemical methods have largely been unsuccessful. This review highlights the key biotic and abiotic challenges in chili farming and explores mitigation strategies.

Prioritizing the development of advanced cultivation techniques, addressing climate-related stressors, and implementing integrated pest and disease management practices is crucial. Among the most effective strategies to combat these viruses is the cultivation of resistant varieties. Both cultivated and wild lines have provided sources of resistance to various viruses, and numerous virus-resistant lines have already been released for cultivation.

Keywords: *Artificial inoculation, begomovirus, chili and virus-resistant*

Highlights:

- Minimize the impact of Chili Leaf Curl Virus (CLCV).
- Increase per-hectare chili yield.
- Emphasize the development of new CLCV-resistant varieties.
- Enhance the economic sustainability of chili cultivation.

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Introduction

This vegetable crop chili (*Capsicum annum* L.) holds significant agricultural importance because of its fruits, which are often used in different forms, including their green and ripe dried forms, for their special trait, *i.e.,* pungency. Capsicum belongs to the genus Capsicum and solanaceous family. Chili is considered to have originated from Southern Peru, Mexico and the Bolivia region of South America (Bosland and Votava, 2012). Five cultivated species of chilies have been identified namely *C. pubescens, C. frutescens, C. chinense, C. baccatum* and *C. annuum*. In five of these *C. annuum* L. is the most popular cultivated species globally, known for both its pungency in chilies or hot peppers and non-pungency in sweet peppers. In the late 15th century Portuguese introduced it in India. China, India, Mexico and Bangladesh are the leading chili-producing nations. In India, chili cultivation is widespread across states like AP, Maharashtra, Karnataka, Odisha, Rajasthan, Punjab, Tamil Nadu and West Bengal, with a combined cultivation area of 804,790 hectares. The overall production is 1,276,300 metric tonnes of chili, which is dry, with productivity of 1.5 mt/ha. AP contributes the most, with 46% of India's overall chili production. (Sharma *et al*., 2018) India plays a significant role in global chili exports, contributing almost a quarter of the total quantity, earning foreign exchange through the chili powder export and oleoresin with varying pungency levels. Currently, 169,500 q of chili, which is dry, worth Rs. 160,408 lakhs, are exported from India, reaching almost ninety countries worldwide.

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Chili is susceptible to approximately 45 viruses, with 24 naturally occurring and the remainder infecting through artificial way of inoculation. Of all 24 naturally occurring viruses, 11 of them are reported in India, including leaf curl virus of tobacco, mosaic virus of cucumber, Indian CMV, potato virus Y, potato virus X ring spot virus of tobacco, vein mottle virus in pepper, vein bending virus in pepper, leaf curl virus of chili, leaf curl New Delhi virus of tomato (LCNDV), and chlorosis virus capsicum, a tospovirus (Kenyon *et al*., 2014; Thakur *et al*., 2018). Recently, CMV of subgroup II has been identified in the Indian western Himalayan region. Pepper husteco virus (PHV) and pepper golden mosaic virus (PepGMV) are two Gemini viruses, earlier named Texas pepper virus, which is considered the major pathogens in pepper in Mexico.

Among these, the CLCV stands out as the most destructive, causing significant damage and yield loss. Sometimes, it may cause approx. 100% loss with serious cases reporting all the marketable fruit has been lost completely. It is essential to estimate all constituents to gain a comprehensive understanding of pathogens.

Biotic Threats

1. Pests

Chili is highly susceptible to a wide range of pests that can cause significant damage Table 1.

2. Diseases

Pathogenic infections can result in severe yield losses Table 2.

Etiology

Researchers have documented the Leaf curl of chili both in India and abroad. The culprits behind this condition were identified as *Polyphagotarsonemus latus* which are mites and *Scirto thrips dorsalis,* which are thrips, according to various investigators. Johnpulle (1939) attributed the cause of leaf curl in chili to these mites and thrips. After observing the prototypical leaf curl trait in 15-25% plants of chili in field conditions, Pal and Tandon, (1937) attributed it to the LCV of tobacco. Subsequently, the leaf curl of chili disease was linked to whitefly (*Bemisiatabaci*) transmitted gemini virus, specifically Pep LCV, which is reported in different countries, including India, the USA, Nigeria alongwith, Pakistan and Indonesia.

Variability in Chilis caused by begomoviruses

A noticeable rise can be seen in recent times about the discovery of begomoviruses, suggesting a long-standing co-evolution with their dicotyledonous host plants. Currently, between 35 to 70 (approx.) Gemini viruses are identified and studied annually. Among all geminiviruses, 200 of them are defined species attributed to begomo viruses, ranking it as the largest of all genera within the family. To date, researchers have identified 34 confirmed and 18 preliminary species of the begomo viruses, which naturally infected the tomato plants. However, the most destructive among these are those categorized under the generic name "tomato leaf curl viruses." 8 different viruses cause Tomato leaf curl disease (To LCD) in India. In which two of them are the tomato leaf curl New Delhi virus (To LCNDV), and tomato leaf curl India virus (To LCIV), and are mostly prevalent in the northern part of India, while tomato leaf curl Karnataka virus (To LCKV) and tomato leaf curl Bangalore virus (To LCBV) are found in the southern part of India. Khan *et al*., (2006) observed an association between To LCNDV and ChiLCV in chili samples that were infected, based on sequencing of fragmentary DNA-A-like components. Nevertheless, the overall order of isolated begomo virus from plants of chili with leaf curl disease in India corresponds the ChiLCV-IN species and shares similarities with the TLCV. This disease results from a complex involving the monopartite ChiLCV and DNA-β satellite-like component.

Symptomatology

The begomoviruses caused by the disease can be recognized very easily by a very clear visual in infected plants with 3 viruses. The main symptoms are of 3 types: yellowing of vein, the yellow mosaic and the last leaf curl. The crinkling of leaf or leaf curl complex was seen on chili which was from India and other countries. The most prominent visual symptoms were the clearing of veins followed by swelling of veins, vein distortion and dorsal side veinlets. The most prominent symptoms consist of leaf curl puckering, rolling, interveinal areas often blistering and the thickening and veins often thickened with swelling, internodes get shortened with the petioles, crowding up of leaves and stunted overall growth of the plants; the older leaves become fragile and leathery. (Fig. 1)

Vector Biology

Whiteflies, which are the members family Aleyrodidae in the order Hemiptera, are minute insects measuring only 1-3 mm. Their name derives from the powdery or flour-like white wax that fully covers their body and wings. While predominantly found in tropical regions, whiteflies are present in warmer areas worldwide, and they pose significant challenges in temperate greenhouse environments. These kinds of pests often feed on plant phloem and cause direct damage to crops by extracting sap and diminishing plant vigor. Moreover, their excretion of honeydew finally leads to the evolution of sooty mold, hindering photosynthesis and potentially reducing harvest quality. Various plant disorders can also be caused by Whiteflies, known as squash silver leaf (*Cucurbitapepo*) and tomato patchy ripening.

Table 1: Summarizes key pests, their symptoms, and management strategies (Hussain *et al*., 2011).

Pest	*Symptoms*	*Management Strategies*
Thrips (Scirtothrips dorsalis)	Leaf curling, stunted growth	Use of insecticides, resistant varieties, sticky traps
Aphids (Aphis spp.)	Yellowing, sooty mold development	Biological control using predators, neem oil sprays
Fruit borers (Helicoverpaarmigera)	Holes in fruits, reduced marketability	Pheromone traps, crop rotation, biopesticides

Table 2: provides a summary of common diseases and their control measures. (Kumar *et al*., 2015).

Disease	*Pathogen*	*Symptoms*	*Control Measures*
Anthracnose	*Colletotrichum* spp.	Black spots on fruits, defoliation	Fungicides, crop residue management
Powdery mildew	*Leveillula taurica*	The white powdery coating on leaves	Sulfur sprays, improved air circulation
Bacterial wilt	*Ralstonia solanacearum*	Wilting, root rot	Resistant varieties, soil solarization

Fig. 1: Leaf curl disease of chili

The Phyto-pathological angle suggests the primary concern with whiteflies lies in their capacity virus transmission, of approx. One thousand five hundred whitefly species, very few of them are vectors for transmitting plant viruses. Notable vectors consist of sweet potato, cotton, tobacco, whitefly (*B. tabaci*), and greenhouse whitefly (*T. vaporariorum*). The most significant vector, which is polyphagous and primarily found in the tropical and semitropical regions, is *B. tabaci*, transmits various viruses like to rhabdoviruses Carla viruses, begomoviruses, ipomoviruses and criniviruses. *T. vaporariorum* is found all over the world in both of greenhouses as well as fields and transmits torrado viruses and criniviruses.

Several distinctions exist within the *B. tabaci* species, known as biotypes, with behavioral differences and genetic differences often identified through different methods such as isoenzyme profiling, mitochondrial COI gene analysis, host preference and virus transmission competency. The biological variations among these biotypes can significantly impact the virus efficiency of transmission, the host range, and mating behavior.

Whiteflies transmit viruses in plants in either a semi-persistent (*e.g.* crini viruses) or persistent (e.g. begomoviruses) manner. Continuous transmission of begomo viruses, such as TYLCV, includes a third partner-chaperonin endosymbiotic bacteria that produce GroEL homologs. While the direct effect of replication within the whitefly vector remains elusive, TYLCV gets transcripted and accumulated in *B. tabaci* and viral DNA quantity appears to increase over time.

The least inoculation and acquisition feeding periods needed for *B. tabaci* to transmit TLCV were determined to be about 30 min each, with a subsequent 6-hour period for the vector to be viruliferous. Individual whiteflies retained infectivity throughout their lifespan without transmission to their progeny. For YLCV, the inoculation and acquisition feeding periods were determined to be 20 and 30 minutes, respectively, with a latent period of 21 to 24 hours.

Transmission Habit

Found that the LCV was transmitted only by A. *nasturtii, M. persicae,* and *A. craccivora*. Husain (1932) recorded the Leaf crinkle or leaf curl observed in chili plants caused by *Bemisiatabaci* and *Bemisiagossypiperda*. The viral basis of this disease was not experimentally proven till 1953, however, when IARI's Ashrafi Jha established it via grafting. Tobacco leaf curl virus (*Ruga tabaci*), which is transmitted by the vector *B. tabaci* was later found to be the cause of leaf curl in chili.

Begomoviruses, known to damage the dicotyledonous plants, are mostly transmitted in a very tenacious way by whiteflies of species *Bemisiatabaci* complex. Due to their phloem inhabitation, begomoviruses are neither sap-transmissible nor seed-transmissible. Successful transmission is achieved with the assistance of whitefly vectors falling out in the family Aleyrodidae. These are pests of both woody plants and herbaceous plants. Whiteflies effectively transmit the virus to the plants falling in the genera *Trialeurodes* and *Bemisia*. In genus *Bemisia, B. tabaci* is the confirmed vector, while in *Trialeurodes* genus, *T. vaporariorum, T. ricini* and *T. abutilonea* have been recognized as transmitters of the virus. The virus Gemini constitutes the biggest and most significant virus group of plants transmitted by vector *Bemisiatabaci*. (Fig.2)

Screening genotypes against leaf curl disease

Chili resistance breeding efforts in India began in the late 1960s, with a primary focus on field conditions to quantify disease prevalence and severity of disease. A coefficient of infection was used to rate diseases, which was determined by multiplying the percentage of disease incidence by the reaction value allocated to each reported disease severity grade. This method showed a good correlation between greenhouse and field assessments. Over the years, numerous chili lines along with different resistance degrees were found, few of them demonstrating tolerance or resistance to different viruses.

PAU, Ludhiana, played a crucial role in developing multiple virus-resistant chili varieties. Notable lines such as BG-1, Perennial, Punjab Lal and Lorai have been identified, and sources

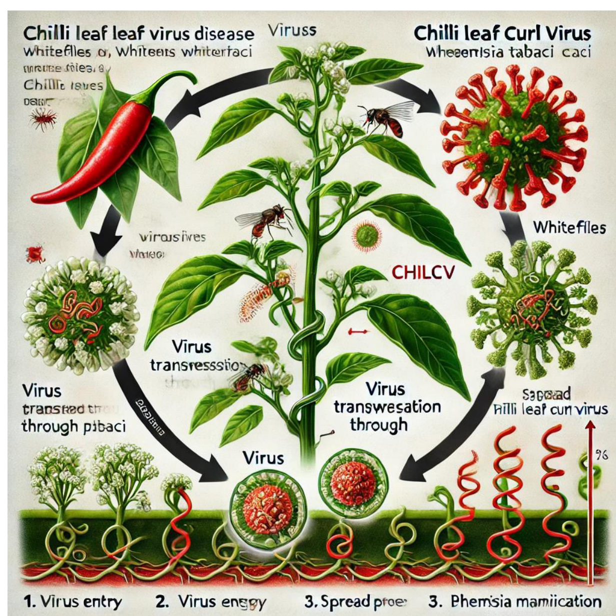

Fig. 2: Mechanism of chili leaf curl disease, including key stages such as virus transmission by whiteflies, viral replication, and symptom manifestation

like these are instrumental in creating high-yielding hybrids like CH-359 and CH-1. Achili variety Pusa Jwala was developed, which is resistant to viruses and then Pant C-1 and Pant C-2. Puri Red, G2, Puri Orange, and Kondiverum cultivars were recognized for their resistance to mosaic through artificial inoculation.

In testing 159 crosses, varieties, selections, LCA-135, Pure Red, Pant C-1, LCA-412, and Cfr-10 were considered to be the most resistant or tolerant to the mosaic-like complex, while others exhibited a very susceptible reaction. Out of 37 chili genotypes 34 of the (*C. annuum*) genotypes screened for LCV incidence, three genotypes (Surya Mukhi, Pusa Jwala, and Loungi) were evaluated as resistant. The use of cultivars remains a prominent strategy for controlling these viruses.

In both cultivated and wild chili lines, several sources of resistance to the virus have been recognized, leading to the release of virus-resistant lines. These lines exhibit resistance to various viruses such as tobacco etch virus (TEV), pepper mottle virus (PeMV) and, potato virus Y (PVY), and a few tobamoviruses. However, challenges persist, especially with viruses like CMV and leaf curl virus complex, posing challenges to breeding programs that are ongoing. (Poveda *et al.,* 2020).

Alternate hosts

Weeds, known for their widespread distribution and high environmental adaptability, have been studied concerning whitefly-transmitted viruses since the 1930s in Latin America. The initial research focused on weed species found in the family of Euphorbiaceae and Malvaceae in Puerto Rico and Brazil. Numerous reports have highlighted the importance of weeds as reservoirs or other hosts for begomovirus existence and spread.

Studies by Sastry, (1984) identified hosts of weeds such as *Parthenium hysterophorus, Datura stramonium, Acanthosperomum hispidum, Ageratum conyzoides, Euphorbia geniculate* and *Gynandropisis pentaphylla,* as the only sources of inoculum for TLCV disease. Various weed species, including *Galinsoga parviflora, Parthenium hysterophorus, Oxalis corniculata, Walteria americana, Synedreallahodiflora, Oxalis acetosella, Solanum nigrum, Cassia uniflora, Euphorbia geniculata*, and *A. conyzoides* were seen harboringbegomoviruses under the natural circumstances. A widespread weed in India, *Partheniumhysterophorus*, was identified as begomovirus reservoir host.

In further studies (PCR) was used to determine begomoviruses in weeds and cultivated crops. These two *Cucumis* sp. and *Tribulus terrestris* were recognized as positive for both CLCBV-CP and DNA-B gene amplification, pointing to their potential role as the only alternate host for cotton leaf curl virus (CLCBV). *Vinca minor* (Periwinkle) and Sunhemp (*Crotolaria juncea*) are also identified as new hosts for begomoviruses in Pakistan and Southeast Asia respectively.

The begomovirus's extensive host range, including its union with TLCNDV, has implications for the epidemiology of the disease-causing virus. The findings underscore the need for a comprehensive management strategy considering the diverse hosts involved. *Clerodendron cyrtophylum* in China has been recognized as a new host for begomovirus, named Clerodendrum golden mosaic Jiangsu virus, which is new. This highlights the ongoing discovery of new hosts and begomoviruses infecting different crops.

Management

A study was conducted on seven insecticides, in which triazophos at a concentration of 0.04% demonstrated the highest effectiveness in the overall management of *Scirtothrips dorsalis* population and helped to prevent the leaf curl effect in chili. Foliar applications of dimethoate (0.03, 0.045%), cypermethrin (0.01, 0.015%) and deltamethrin (0.0028, 0.0042%) were very effective in minimizing whitefly incidence in fields of green gram. The seed kernel of Neem extracted at 5% concentration proved to be more effective than the extracts from Karanj and Tumba seeds. Imidacloprid 17.8 SL (0.003%) outperformed 25 EC (0.025%) Methyl-demeton and 50 EC (0.05%) Malathion in managing whiteflies.

In another study, the application of dry powder from *Clerodendron aculeatum* as a soil amendment, coupled with six times weekly foliar spray, resulted in a two-fold rise in the nodulation and grain yields, along with almost half reduction in yellow mosaic of mung bean incidence.

Biological control methods included the use of parasitoids from the *Encarsia* and *Eretmocerus* genera, along with predators from various families. However, different cultural and chemical practices for controlling ChiLCV have not proven to be sufficient and very effective either. (Poveda *et al.,* 2020). The only effective method found to date is the planting of resistant cultivars which proved to have the highest success rate in controlling the virus. There are so many sources of virus resistance that have been identified in due course of time, both in the wild lines and cultivated lines, which lead to the release of several virus-resistant lines as part of ongoing efforts to combat these viruses.

Conclusion

Chili, belonging to the Solanaceae family and the Capsicum genus, holds immense global agricultural importance. However, it faces significant challenges due to its susceptibility to approximately 45 viruses, with chili leaf curl virus (CLCV) being the most destructive, causing severe yield losses. Efforts to screen genotypes for resistance have identified several virus-resistant varieties. Breeding programs, particularly at PAU, Ludhiana, have developed promising virus-resistant lines, offering an effective approach to virus management.

Weeds have been identified as alternate hosts for whitefly-transmitted viruses, highlighting the importance of a comprehensive management strategy that addresses diverse hosts. From a management perspective, insecticides such as triazophos and neem seed kernel extract have proven effective against vectors like *Scirtothrips dorsalis* and *Bemisia tabaci*. Biological control methods using parasitoids and predators have also been explored, but the cultivation of resistant varieties remains the most successful strategy.

Understanding the epidemiology, etiology, and management strategies of chili viruses is vital for sustainable chili production and addressing these challenges. Ongoing research continues to shed light on the complex interactions between chili plants, viruses, and vectors, paving the way for improved agricultural practices and enhanced food security.

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Authors Contribution

AS: Planning of the study, critical review, and editing of the manuscript. SS Conceptualization of the idea and overall supervision of the study. SR Review and editing of the manuscript, incorporating suggestions from reviewers and editors. ES Addressing corrections as per suggestions from reviewers and editors. KS & AS Conceptualization of the idea, drafting the original manuscript, conducting a literature review, and compiling the study findings.

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