

Chilli Leaf Curl Virus an Emerging Threat to Chilli in India

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ABSTRACT

Chilli is known to be affected by forty five viruses. Twenty four of them have been reported to occur naturally and rest can infect on artificial inoculation. Among the twenty four viruses reported to occur naturally on chilli, eleven viruses have been reported from India. Among all, the chilli leaf curl virus is the most destructive virus in terms of incidence and yield loss. In severe cases 100 percent losses of marketable fruit have been reported. Chilli leaf curl locally known as murda is a most destructive disease of chilli in India. However, the viral nature of the disease has not been proved experimentally until Ashrafi Jha from IARI established this by grafting, later it was proved that leaf curl of chilli is caused by tobacco leaf curl virus (*Ruga tabaci*) which is transmitted by vector *B. tabaci*. The diseases caused by begomoviruses are easily recognized by their distinctive symptoms in plants infected with these viruses. The symptoms are broadly of three types: a) vein yellowing, b) yellow mosaic and c) leaf curl. Control of ChiL CV viruses by chemicals or cultural management practices has not been very effective. The planting of resistant cultivars offers the best way to control these viruses. A number of sources of virus resistance have been reported in wild and cultivated lines and several virus-resistant lines have already been released. Many multiple virus-resistant varieties have been developed at Punjab Agricultural University, Ludhiana. Important multiple resistant lines are Perennial, BG-1, Lorai, and Punjab Lal. Weeds act as potential sources of begomoviruses, several weed families particularly Malvaceae have been found to harbor viruses.

Key words: Chilli leaf curl, begomo viruses and *B. tabaci* and management.

INTRODUCTION

Chilli (*Capsicum annuum* L.) is an important spice grown for its fruits, which are used in green as well as ripe dried form for its pungency. Chilli belongs to the genus

Capsicum, family Solanaceae. It has originated in Mexico, Southern Peru and Bolivia⁷¹. There are mainly five cultivated *Capsicum* spp. viz. *C. annuum*, *C. baccatum*, *C. chinense*, *C. frutescens*, and *C. pubescens*.

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Among these, *C. annuum* L. is the most widely cultivated species all over the world for its pungent (chilli syn. Hot pepper) and non-pungent (sweet pepper) fruits. Chilli crop is raised over 1832 thousand hectares in the world, with a production of 2959 thousand tonnes⁴. Highest production per unit area of 36,585 kg per ha was recorded in Japan⁴. It was first introduced in India by Portuguese towards the end of 15th century. The top ten chilli producing countries India, China, Ethiopia, Myanmar, Mexico, Vietnam, Peru, Pakistan, Ghana and Bangladesh accounted for more than 85% of the world production in 2009; lion's share is taken by India with 36% share in global production, followed by China (11%), Bangladesh (8%), Peru (8%) and Pakistan (6%)⁴. In India Chilli is cultivated in all the states including Andhra Pradesh, Karnataka, Maharashtra, Orissa, Rajasthan, Tamil Nadu, West Bengal and Punjab over an area of 804790 hectares with total production of 1276300 metric tonnes of dry chilli with productivity of 1.5 metric tonnes per hectare. Andhra Pradesh alone contributes 46 per cent of total chilli production of India. India contributes one-fourth of the total quantity of chilli exported in the world⁴. Tremendous foreign exchange is being earned through export of chilli powder, oleoresin of low, medium or high pungency. At present 169500 quintals of dry chilli of the worth of Rs 160408 lakh is exported from the country⁴. Indian chillies are exported to over 90 countries in the world⁴. If some varieties are famous for red colour because of the pigment capsanthin, others are known for biting pungency attributed by capsaicin. It is a rich source of vitamins A and C. India is the only country rich in many varieties with different quality factors. World's hottest chilli "Naga Jolokia" is cultivated in hilly terrains of Assam in a small town Tezpur, India⁴. Chilli is known to be affected by forty five viruses²⁰. Twenty four of them have been reported to occur naturally and rest can infect on artificial inoculation. Among the twenty four viruses reported to occur naturally on chilli, eleven viruses have been reported from

India, viz., cucumber mosaic virus, tobacco leaf curl virus²⁵, Indian chilli mosaic virus, potato virus Y, potato virus X, tobacco ring spot virus, pepper veinal mottle virus and pepper vein bending virus, chilli leaf curl virus, tomato leaf curl New Delhi virus³⁰, capsicum chlorosis virus a tospovirus. Recently cucumber mosaic virus subgroup II has been reported to infect chilli⁶ from western Himalayan region of India. In Mexico, two Gemini viruses are considered to be the main pathogens in pepper i.e. pepper huasteco virus (PHV) and pepper golden Mosaic virus (PepGMV) formerly called Texas pepper virus. Among all, the chilli leaf curl virus is the most destructive virus in terms of incidence and yield loss. In severe cases 100 percent losses of marketable fruit have been reported³³.

CHILLI LEAF CURL VIRUS

The etiology of chili leaf curl disease was reported during the 1960s¹³. Since it is a begomovirus and it is transmitted in a persistent manner by white flies of the species complex *Bemisia tabaci*⁷. The typical symptoms consisting of leaf curling, rolling, puckering, blistering of interveinous areas and thickening and swelling of the veins, shortening of internodes and petioles, crowding of leaves and stunting of whole plants, older leaves may become leathery and brittle⁶⁰.

Chilli leaf curl locally known as murda is a most destructive disease of chilli in India. The etiology of chili leaf curl disease was reported during the 1960s¹³. Mites (*Polyphagotarsonemus latus*) and thrips (*Scirtothrips dorsalis*) were considered to be responsible for causing chilli leaf curl symptoms⁴². Johnpulle²⁸ considered it to be caused by both mites and thrips. Amin³ concluded that leaf curl in chilli was due to feeding of thrips and mites and not by an infectious agent. However, the viral nature of the disease has not been proved experimentally until Ashrafi Jha from IARI in 1953 established this by grafting, later it was proved that leaf curl of chilli is caused by tobacco leaf curl virus (*Ruga tabaci*) which is transmitted by vector *B. tabaci*⁵⁶.

Based on partial DNA-A sequences, a monopartite begomovirus was reported to be associated with the disease which was a strain of the Chili leaf curl virus (ChiLCV) from Pakistan³⁰.

VARIABILITY IN BEGOMOVIRUSES INFECTING CHILLI

There has been a tremendous increase in the number of begomoviruses that have been isolated in recent years as these are assumed to have been co-evolving with their dicotyledonous plant hosts for a long time⁵⁴. Currently, 35-70 geminiviruses are being discovered and characterized every year. Out of the total geminiviruses, 200 defined species belong to begomoviruses, thus making it the largest genus in the family.

So far, 34 recognized and 18 tentative species of begomoviruses have been found to naturally infect tomato. However, the begomoviruses with generic name 'tomato leaf curl viruses are the most devastating viruses. In India, eight different viruses cause Tomato leaf curl disease (ToLCD). Three of these viruses, tomato leaf curl Gujarat virus (ToLCGV), tomato leaf curl India virus (ToLCIV) and tomato leaf curl New Delhi virus (ToLCNDV) occur in northern India while the other two, tomato leaf curl Bangalore virus (ToLCBV) and tomato leaf curl Karnataka virus (ToLCKV) occur in southern India³⁸. Khan³⁰ found the association of ToLCNDV and chilli leaf curl virus (ChiLCV) in the infected samples of chilli showing leaf curl disease based on the partial sequencing of a DNA-A like component. However, the full length sequence of a begomovirus isolated from plants with chilli leaf curl disease in India belongs to the species ChiLCV-IN and has been found to be similar to tomato leaf curl Joydebpur virus⁵⁸. Chilli leaf curl disease is caused by a complex consisting of the monopartite chilli leaf curl virus and a DNA-β satellite component.

SYMPTOMATOLOGY

The diseases caused by begomoviruses are easily recognized by their distinctive symptoms in plants infected with these viruses. The symptoms are broadly of three

types: a) vein yellowing, b) yellow mosaic and c) leaf curl. Leaf crinkle or leaf curl complex was observed on chillies from India and abroad²⁵. Curling of leaf margin, reduction in leaf size, vein clearing were observed in India, Sri Lanka and USA⁴⁶. Abaxial curling of the leaves accompanied by puckering, thickening and swelling of the veins were observed by many study. Appearance of most prominent symptoms such as vein clearing followed by veinal distortion, swelling of veins and veinlets on dorsal side. The typical symptoms consisting of leaf curling, rolling, puckering, blistering of interveinous areas and thickening and swelling of the veins, shortening of internodes and petioles, crowding of leaves and stunting of whole plants, older leaves may become leathery and brittle⁶⁰.

OCCURRENCE

Leaf curl of chilli has been reported by several investigators from India and abroad²⁵. However, the virus nature of the disease has not been proved experimentally by them. Park and Fernando⁴² questioned the virus nature of disease. Pruthi and Samuel⁴⁴ observed typical leaf curl symptoms on 15-25% of chilli plants under field conditions and they considered it to be caused by the Leaf curl virus of tobacco reported by Pal and Tandon³⁹. Latter on chilli leaf curl disease caused by whitefly (*Bemisia tabaci*) transmitted (WFT) geminivirus, namely, pepper leaf curl virus (PepLCV) was reported from India³⁵, United States⁶³, Nigeria² and several other countries such as Pakistan, and Indonesia¹⁵.

LOSSES

The emerging threat of the viruses belonging to the genus Geminivirus has been extensively addressed earlier. The extent of yield loss caused by some geminiviruses has been estimated as high as 100% and in some areas infection with viruses has rendered the growing of peppers uneconomical, causing whole fields to be abandoned prior to harvest²¹. Up to 96% loss in yield has been reported by Bhendi yellow vein mosaic virus⁴⁵. In legumes, the yield losses have been estimated to be approximately \$300 million per year taking black gram, mungbean and

soybean together. Economic losses due to geminivirus infections in Cassava are estimated to be US \$ 1300-2300 million in Africa⁶⁷, US \$ 5 billion for cotton in Pakistan between 1992-97, US \$ 300 million for grain legumes in India⁷⁰, and US \$ 140 million in Florida for tomato alone. Tomato leaf curl and tomato yellow leaf curl diseases are widespread in more than 20 countries; it caused heavy yield losses and wiped out tomato crops in some areas²⁰. Saikia and Muniyappa⁵⁰ reported more than 90% fruit yield loss due to tomato leaf curl disease when infection occurred within four weeks of transplanting.

ETIOLOGY

Leaf curl of chilli has been reported by several investigators from India and abroad. Mites, *Polyphagotarsonemus latus* and thrips, *Scirtothrips dorsalis* were considered to be responsible for causing chilli leaf curl symptoms⁴². Johnpulle²⁸ considered that chilli leaf curl disease is caused by mites and thrips. Pruthi and Samuel⁴⁴ observed typical leaf curl symptoms on 15-25% of chilli plants under field conditions and they considered it to be caused by the Leaf curl virus of tobacco reported by Pal and Tandon³⁹. Later on chilli leaf curl disease caused by whitefly (*Bemisia tabaci*) transmitted (WFT) geminivirus, namely, pepper leaf curl virus (PepLCV) was reported from India⁴⁷, United States⁵⁵, Nigeria² and several other countries such as Pakistan, and Indonesia¹⁵.

TRANSMISSION

Transmission of Leaf curl virus through *M. persicae*, *A. nasturtii* and *A. craccivora* was reported by Szalay⁶⁴. Leaf curl or leaf crinkle occurring on chillies transmitted by *Bemisia tabaci*, *Bemisia gossypiperda* has been reported by Husain²⁵. However, the viral nature of the disease had not been proved experimentally until Ashrafi Jha from IARI in 1953 established this by grafting, later it was proved that leaf curl of chilli is caused by tobacco leaf curl virus (*Ruga tabaci*) which is transmitted by vector *B. tabaci*³⁹. Begomoviruses infect dicotyledonous plants and are transmitted in a persistent manner by

white flies of the species complex *Bemisia tabaci*⁷. As the begomoviruses are phloem inhabited, so they are neither sap transmissible nor seed transmissible. They are successfully transmitted with the help of whitefly vector belonging to family *Aleyrodidae* which are the pests of herbaceous and woody plants. The plant viruses are successfully transmitted by whitefly belonging to genus *Bemisia* and *Trialeurodes*. In the genus *Bemisia*, only *B. tabaci* has been shown to be vector whereas in the genus *Trialeurodes*, *T. vaporariorum*, *T. abutilonea*, and *T. ricini* transmit viruses. The largest and most economically significant groups of plant viruses transmitted by *Bemisia tabaci* are the Gemini viruses.

WHITEFLY AS A VECTOR

Whitefly belongs to family *Aleyrodidae* (order Hemiptera). It is a tiny insect, only 1–3 mm long. The wings and bodies of the adults are covered with a powdery or flour-like white wax thus called whiteflies. On most host crops, eggs are laid and immature stages develop on the abaxial surface of leaves. Although they are mainly tropical insects, whiteflies are found in all warmer parts of the world, and several are also serious pests in greenhouses in temperate areas. Direct crop damage occurs when whiteflies feed in plant phloem, remove plant sap, and reduce plant vigor. Whiteflies also excrete honeydew, which promotes sooty mold that interferes with photosynthesis and may lower harvest quality. In some hosts, damage can result from whitefly feeding toxins that cause plant disorders such as silver leaf of squash (*Cucurbita pepo*)⁸ and irregular ripening of tomato⁵³. From a phytopathological perspective, however, the main concern about whiteflies is their ability to transmit viruses. Of the approximately 1,500 species of whiteflies³⁶, only a few have been shown to vector plant viruses, and these vectors include the cotton/tobacco/sweet potato whitefly [*B. tabaci* (Gennadius)] and the greenhouse whitefly (*T. vaporariorum* Westwood). *B. tabaci*, by far the most important whitefly in terms of virus transmission, is typically polyphagous, is generally found in tropical and

semiotropical regions, and vectors begomoviruses, criniviruses, carlaviruses, ipomoviruses, and torradoviruses. *T. vaporariorum* is also polyphagous, is found nearly worldwide in both greenhouses and fields, and transmits criniviruses and torradoviruses. The banded winged whitefly [*T. abutiloneus* (Haldeman)] is also a vector of a number of criniviruses. The castor bean whitefly [*Trialeurodes ricini* (Misra)] has been reported to be a vector of the begomovirus *Tomato yellow leaf curl virus* (TYLCV) in Egypt²⁶, but this finding has not yet been confirmed. Also, *Bemisia afer* sensu lato has recently been described as a vector of the crinivirus *Sweet potato chlorotic stunt virus*. *B. tabaci* corresponds to a complex of genetic variants or haplotypes, usually referred to as biotypes. Based on mitochondrial cytochrome oxidase subunit (COI) gene consensus sequences, a recent report has suggested that *B. tabaci* is a complex of at least 24 distinct cryptic species¹⁴. Although no morphological characteristics can be used to distinguish between *B. tabaci* populations, genetic and behavioral differences have been used for haplotype/biotype characterization. These include isoenzyme profiling, bar-coding based on conserved genes like the mitochondrial COI gene, life history traits, host range and/or host preference, virus transmission competency, composition of endosymbionts, dispersal behavior, insecticide resistance, and discontinuous gene flow⁸. Biological differences between *B. tabaci* biotypes can radically affect the emergence of a virus disease by causing differences in transmission efficiency, host range, or mating behavior, as is discussed below. Whiteflies can transmit plant viruses in a semipersistent manner (e.g., criniviruses) or a persistent manner (e.g., begomoviruses). Interestingly, the persistent transmission of some begomoviruses involves a third partner. Thus, persistent transmission of TYLCV by *B. tabaci* depends on chaperonin GroEL homologs produced by endosymbiotic bacteria³⁶. Whether the persistent transmission of begomoviruses is propagative (i.e., the virus replicates in the insect vector) or only

circulative is controversial, and the only data available have been obtained with TYLCV. Thus, although no direct evidence of replication has been obtained so far, TYLCV transcripts accumulate in *B. tabaci* and the quantity of viral DNA seems to increase with time in the insect following an acquisition period on infected tomato plants¹¹. The minimum acquisition and inoculation feeding period required by *B. tabaci* to transmit tomato leaf curl virus was found to be 30 minutes each. After acquisition the vector required 6 hours to become viruliferous. Single whitefly was able to transmit the virus. The whiteflies remained infective throughout their life span; the virus was not transmitted to the progeny of the whitefly⁹. The minimum acquisition and inoculation – feeding periods for the vector, *Bemisia tabaci* to transmit yellow leaf curl virus was 20 and 30 minutes, respectively. The latent period was 21-24 hours.

MANAGEMENT

The foliar application of cypermethrin (0.01, 0.015%), deltamethrin (0.0028, 0.0042%) and dimethoate (0.03, 0.045%) was effective in reducing the whitefly incidence in green gram field. In a study carried out with seven insecticides, triazophos 0.04 per cent was most effective for managing populations of *Scirtothrips dorsalis* and preventing incidence of leaf curl in chilli⁴¹. Neem seed kernal extract (5%) was found most effective than Karanj and Tumba seed extract. Insecticide Imadalcoprid 17.8 SL (0.003%) was found effective than Malathion 50 EC (0.05%) and Methyl-demeton 25 EC (0.025%) in the management of Whiteflies⁴⁰. Two fold increase in nodulation and grain yield with 50% reduction in mung bean yellow mosaic incidence in mung bean when dry powder of *Clerodendron aculeatum* was applied as soil amendment in addition to six times foliar spray at weekly interval⁷⁰. Biological control includes use of parasitoids of genera *Eretmocerus* and *Encarsia* and predators belonging to numerous families⁵. Control of ChiLCV viruses by chemicals or cultural management practices has not been very effective. The planting of resistant

cultivars offers the best way to control these viruses. A number of sources of virus resistance have been reported in wild and cultivated lines and several virus-resistant lines have already been released. Among these are lines with resistance to potato virus Y (PVY), tobacco etch virus (TEV), pepper mottle virus (PeMV) and certain tobamoviruses. However, other viruses, particularly cucumber mosaic virus (CMV) and the leaf curl virus complex, continue to pose a challenge to breeding programs.

SCREENING OF PEPPER GENOTYPES AGAINST LEAF CURL DISEASE

In India, breeding for resistance in chilli was started in the late sixties but most of the screening has been under field conditions, assessing disease incidence and disease severity. For disease rating, a coefficient of infection has been used, for which the percentage disease incidence was multiplied with a response value assigned to each observed disease severity grade. A good correspondence was usually obtained between field and greenhouse assessments³⁴. Since then, a number of lines with varying degrees of resistance have been identified; some of these lines also exhibit resistance or tolerance to other viruses⁶⁶. Many multiple virus-resistant varieties have been developed at Punjab Agricultural University, Ludhiana. Important multiple resistant lines are Perennial, BG-1, Lorai, and Punjab Lal⁵⁹. These sources have been used for development of high yielding hybrids of chilli like CH-1 and CH-3. Pusa Jwala, a chilli variety resistant to virus was developed by Tewari and Ramanujam⁶⁵ followed by Pant C-1 and Pant C-2. Cultivars Puri Red, Puri Orange, G2 and Kondiverum were known to be resistant to mosaic by artificial inoculation. Out of one hundred and fifty nine varieties/crosses/selections tested, Pure red, Cfr-10, LCA-135, LCA-412 and Pant C-1 were found to be resistant /tolerant to mosaic complex, whereas others showed susceptible reaction²⁷. 37 chilli (*Capsicum annuum*) genotypes were screened for the incidence of leaf curl virus, 3 (Pusa Jwala, Surya Mukhi and Loungi) were rated resistant,

2 moderately resistance, 19 susceptible and 13 highly susceptible³¹. The F1 progenies and BC2 generations of certain crosses were found to be resistant for leaf curl complex. However, the BC1 generation of the cross, (Punjab lal x Pusa sadabahar) x Punjab lal, was found to be highly resistant with a much reduced coefficient of infection. Plants collected in thirteen wild populations of *Capsicum annuum* from Northwest Mexico were tested for resistance to the pepper huasteco begomovirus (PHV) that is transmitted by the whitefly *Bemisia tabaci* Genadius. Plants of only two of the populations either did not develop disease symptoms after inoculation⁵⁵. Two varieties of chilli (Puri Red and Puri Orange) were found resistant to chilli leaf curl virus upon subjecting to viruliferous white flies under artificial screening. The results were further confirmed by grafting the scion from typically leaf curl affected chilli plants on the stocks of Puri Red and Puri Orange varieties³⁵. Pant C1 and Pant C2 showed significantly higher yields compared to the better parent viz. NP-46A by way of plot average as well as plant yield. Leaf curl incidence was significantly lower in both these varieties compared to NP-46A, especially in case of Pant C1. Jawala, a selection developed from the cross N.P. 46-A x Puri Red was found to be promising against leaf curl disease. Sangar⁵¹ reported that the varieties JCA-248, JCA-218, Pant C-1, NP-46, Pusa Jawala and JCA-196 were resistant against chilli leaf curl virus. GKC-29, BS-35 and EC-497636 genotypes showed no symptoms of leaf curl and they were further subjected to grafting with scions of susceptible Pusa Jwala and later on to PCR amplification, the three lines didn't show any amplification confirming absence of viral genome were declared as symptomless genotypes³². Pusa Jawala, Surajmukhi, Janani lounge and JCA-196 were found resistant against Chilli leaf curl virus³¹. These sources have been used for the development of high yielding hybrids of chilli like CH-1 and CH-3. Kumar³² screened three hundred and seven genotypes belonging to four cultivated and one wild species of *Capsicum* against pepper leaf curl virus

(PepLCV) out of which only three genotypes viz., GKC-29, BS-35 and EC-497636 were found resistant. EC 4020, EC 6589, EC 7299, ED 7338, EC 9293, Puri Red and Puri Orange -field resistant to leaf curl virus, Surjamani and Perennial resistant to leaf curl virus also resistant to chilli mosaic. S 118, S 114 (derived from Perennial x Long Red) resistant to resistant to ChLCV⁶². Jwala (derived from Puri Red and N.P. 46A) resistant to ChLCV and mosaic. *C.annuumn* var. *angulosumn* tolerant to leaf curl virus also tolerant to CMV, Pusa Jwala also resistant to TMV, susceptible to CMV. Delhi Local tolerant to leaf curl virus also tolerant to TMV, immune to CMV and PVX and *C.annuum* S 38-3-19, S42-2-4 - tolerant to leaf curl virus -also tolerant to PVX and CMV⁶⁶. Despite efforts by various research groups, it was not possible to establish genetic control of the resistance gene(s). This could be attributed to shortcomings in screening techniques, virus detection methods, variability of virus causing leaf curl disease etc. To sustain production and enhance profitability of chilli cultivation, it is important to identify confirmed sources of resistance and utilize them in resistance breeding programme by employing conventional and molecular breeding approaches.

ALTERNATE HOSTS

Weeds are widely distributed in the world and have high environmental adaptability. The first studies of whitefly transmitted viruses in Latin America date from 1930s and concern several weed species in the families Malvaceae and Euphorbiaceae in Puerto Rico and Brazil¹⁰. Many reports have demonstrated that weeds serve as reservoir or alternative hosts for begomovirus survival and spread. Sastry⁵² reported that weed hosts such as *Acanthospermum hispidum*, *Ageratum conyzoides*, *Parthenium hysterophorus*, *Datura stramonium*, *E. geniculata* and *Gynandropisis pentaphylla* as sources of inoculum for tomato leaf curl virus disease. Valand and Muniyappa³⁷ studied the host range of tobacco leaf curl virus and found virus was transmissible to nine crop plants, eight ornamental plants and eighteen weed

hosts. *A. conyzoides* L., *Oxalis acetosella* L., *Oxalis corniculata* L., *Euphorbia geniculata* L., *Synedrella hodiflora* L., *Galinsoga parviflora* Cav., *Solanum nigrum* L., *Cassia uniflora* L., *Parthenium hysterophorus* L. and *Walteria americana* L. in all the seasons with high disease incidence during summer compared to Kharif and rabi. The highest ToLCV incidence (37.68 %) was recorded on *Euphorbia geniculata* L., reported to be one of the reservoir hosts for ToLCV Rhynchosia mosaic geminivirus, whose natural host is *Rhynchosia minima*, was transmitted to beans in which it caused typical mosaic, dwarfing and leaf distortion¹⁹. Ramappa⁴⁸ reported more than 30 weed species to harbour begomoviruses under natural conditions. Kang²⁹ reported the presence of cotton leaf curl virus in symptom less plants of chilli and China rose using polymerase chain reaction. Reddy⁴⁹ has reported *Parthenium hysterophorus*, a wide spread weed in India, as a reservoir host of begomovirus.

Sivalingam⁶¹ tested seven weed and three cultivated crop plants for the detection of begomoviruses by polymerase chain reaction using universal DNA-β primers of begomoviruses and primers specific to the coat protein gene of begomoviruses infecting cotton (CLCBV-CP) and out of these, only two weed species *Tribulus terrestris* and *Cucumis* sp. were found to be positive for both DNA-B and CLCBV-CP gene amplification which were not showing any visible symptoms in the field. This indicated that these weed species are the probable alternate hosts for CLCBV.

Gupta²³ tested the efficiency of *Bemisia tabaci* (Gennadius) populations collected from different plant-hosts viz., cotton, potato, tomato, soybean, brinjal and weed (*Sida* sp.) and reported that whitefly from different hosts can efficiently transmit the virus to cotton if it has been successfully acquired by the whitefly.

Sivalingam⁶¹ identified carrot (*Daucus carota*) as a new host for begomoviruses causing yellow mosaic disease of carrot in the states of Uttar Pradesh, Haryana and Punjab.

The nucleotide similarity index of the engaged viruses showed the association of Tomato leaf curl New Delhi virus. These viruses have also been reported to infect *Duranta* species in India⁵⁷ as well as in Pakistan.

Perveen⁴³ detected the presence of begomoviruses in aksan, hulhul, lehli, itsit, bhakra, tandla, shoe flower (*Hibiscus rosasinensis*), okra, brinjal and chilli using triple antibody sandwich enzyme linked immunosorbent assay (TAS-ELISA).

Recently, Tiwari⁶⁸ identified four different species of begomoviruses on the basis of cloning and sequencing of 800 bp fragment in different cucurbit crops in UP. Based on highest (97–99%) sequence identities and closest phylogenetic relationships, four representative Begomovirus species were identified as Ageratum enation virus (from *Trichosanthes dioica*), Squash leaf curl China virus (from *Cucurbita maxima*), Tomato leaf curl New Delhi virus (from *Momordica charantia*, *Luffa cylindrica* and *Luffa acutangula*) and Tomato leaf curl Palampur virus (from *Cucurbita pepo*). Their findings suggested the existence of a high genetic diversity among begomoviruses infecting cucurbitaceous crops.

In China, *Clerodendron cyrtophyllum* has been reported to be a new host for begomovirus. The sequence characterization studies revealed the association of a distinct begomovirus with *C. cyrtophyllum* showing yellow mosaic type of symptoms. The new virus has been given a name as Clerodendrum golden mosaic Jiangsu virus.

Ahmad and Saeed¹ investigated the role of tomato crop as a potential host for cotton leaf curl virus. Ahmad¹ identified sunhemp (*Crotalaria juncea*) as a new host for begomoviruses in SouthEast Asia. Haider²⁴ reported the association of begomovirus with *Vinca minor* (Periwinkle) showing yellowing and leaf curl type of symptoms in Pakistan. Gaikwad^{16,17,18} reported Brinjal, *Petunia hybrida*, Calendula and Marigold as a natural host for the tomato leaf curl virus in India. The extensive host range has consequences for virus disease epidemiology and is worth considering while developing a system-wide management strategy for these viruses.

Pumpkin (*Cucurbita maxima*) and snap melon (*Cucumis melo momordica*) act as potential reservoirs of begomoviruses as they remain in the field for long. The *Euphorbian Mosaic Virus* (EuMV) was found naturally infecting pepper in Mexico²². In Cuba, Begomoviruses also frequently infect and induce conspicuous golden mosaics in weeds *Rhynchosia minima* (family leguminosae) and *Malvastrum coromandelianum* (family malvaceae). Begomovirus diversity is probably highest in Latin America and the the Caribbean, where these viruses have many wild hosts belonging to family malvaceae³⁶.

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