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Review Article

Top Ten Viruses Reported on Chilly in Southeast Asia

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ABSTRACT

Chilly is a common spice crop grown in large quantities in South Asia. India produces 75% of the total chilly crop followed by Nepal at 8% and Bangladesh at 6%, where it is grown primarily by large and small-scale farmers. It can also be found in the kitchen garden. Disease and insect pests are the most significant factors affecting the production of the chilly crop. The viral disease represents a significant threat to chilly production. Recently, 68 viruses have been reported influencing the chilly crop all over the world. Chilly Leaf Curl Virus Disease, Cucumber Mosaic Virus, Tobacco Mosaic Virus, Tomato Spotted Wilt Virus, Potato Virus Y, Alfalfa Mosaic Virus, Pepper Vein Mottle Virus, Beet Curl Top Virus, and Pepper Mild Mottle Virus are among the 68 viruses belonging to seven genera namely, *Begomovirus, Cucumovirus, Tobamovirus, Tospovirus, Potyvirus, Alfamovirus and Curtovirus.* In chilly cultivation, yield losses vary from 15 to 100%, depending on the virus. This review article is an analysis providing of top ten viruses reported in Chilly, including their geographic range, yield losses, symptomatology, transmission and management in South Asian Countries.

Keywords: Chilli; South-Asia; Chilly leaf curl virus; Tobacco mosaic virus; Cucumber mosaic virus; Yield loss

INTRODUCTION

Chilly belongs to the genus Capsicum, under *Solanaceae* family. It is an important fruit vegetable, and spice, with a frequently sharp taste and attractive appearance, so it is grown all over the world [1]. Since the introduction of the chilly crop in South Asian countries in the 16th century, the climate of the region has been favourable for its cultivation. The production of green and dry chilli across the world in 2019 was approximate 38652669 tons (FAOSTAT. 2019). India produces 1743000 tonnes of dry chilli and 81837 tonnes of green chilli. The top five chilly producing countries in South Asia in 2019 was India, Nepal, Bangladesh, Pakistan, and Iran, with a total production of 1824837, 187629, 149473, 101659, and 100232 tonnes (FAOSTAT 2019) (Table 1). Chilly is a cash crop in South Asia, it contributes to the economy in a various of ways, including as a source of income and job creation. Particularly to the rural population and foreign earners. Recognizing the importance of chilly as a cash crop in South Asia and around the world, the constraint to its production is reviewed with the goal of addressing them. High seed costs, a lack of proper and appropriate inputs, a lack of improved varieties, drought stress, low soil fertility, a lack of storage facilities, price volatility, a lack of technical knowledge at the farm level, and extreme disease are some of the major constraints. The most devastating factors in the production of chilly crop are viral diseases, which cause serious economic losses to chilli cultivators. In this review we are reporting a wide range of viral diseases which affects the chilli crop in all South Asian countries, including India.

Table 1: Total chilli (Area harvested/Yield/Production) in South-Asian countries (Source of Data: FAOSTAT,2019).

S.N.	Country name	Area Harvested (ha)	Yield(hg/ha)	Production (tones)
1.	India	789892	23102	1824837
2.	Nepal	22824	82206	187629
3.	Bangladesh	96800	15441	149473
4.	Pakistan	47349	21470	101659
5.	Iran	7922	126523	100232
6.	Srilanka	10504	56259	59095
7.	Bhutan	3643	56091	20434
8.	Maldives	28	23571	66
9.	Afghanistan	-	-	-

LITERATURE REVIEW

This is a retrospective and descriptive study based on the medical records of patients seen in dermatology consultations over the period from January 1, 2010 to December 31, 2020 (10 years). Included were patients of all ages and both sexes in whom a positive diagnosis of onychomycosis was made, based on clinical and mycological examinations. Only complete patient files were retained. Data was collected on the basis of a technical sheet including the study variables: the socio-demographic data of the patients, clinical and mycological (Table 2).

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Table 2: Details of top ten viruses reported in chilly in South Asian Countries

SN	Virus	Genus	Family	Common symptom	Transmission	Genome Type	Country Reporter	References
1	Chilli Leaf Curl	Begomovirus	Geminiviridae	Curling of leaf, Puckering, Blistering & swelling of vein	Aphid		India, Pakistan, & Nepal	Thakur et al., 2018; Senanayake and Dassanayake, 2015
2	Cucumber Mosaic	Cucumovirus	Bromoviridae	Mild Mosaic, Yellow mottling, Vein banding, Vein clearing, stunted growth & Reduce fruit size	Aphid, Seed & Mechanical	ssRNA	India, Pakistan, Bangladesh Nepal & Iran	Venkatesh et al., 2019; Ashfaq et al., 2014; Rahman et al., 2016; Ali and Kobayashi, M. (2010).
3	Tobacco Mosaic	Tobamovirus	Virgaviridae	Curling of leaf, Leaf Mosaic, stunted growth & Reduce fruit size	Seed & Mechanical	ssRNA	India, Bangladesh, Pakistan ,Nepal Iran Srilanka, & Bhutan,	Alishiri et al., 2013; Shrestha et al., 2018; Akhatar et al., 2019
4	Tomato Spotted	Tospovirus	Bunyauitidae	Curling of leaf, Wilting, Necrotic & Chlorotic spots &Necrotic streak on stem	Thrips & Mechanical	ssRNA	India, Nepal, Bangladesh Pakistan, & Iran	Bidari and Reddy, 1990; Ashfaq and Ahmad, 2017; Green, 1993
5	Potato VirusY (PVY)	Potyvirus	Potyviridae	Vein clearing Vein banding, Mosaic, mottling, inter-veinal chlorosis, stunted height	Aphid, & Mechanical	ssRNA	India, Pakistan, Bangladesh, Nepal, Iran & Srilanka	Rahman et al., 2016; Paudel and Khanal, 2018; Hosseini et al., 2011
6	Alfalfa Mosaic Virus (AMV)	Alfamovirus	Bromoviridae	Bright Yellow and Bronchy Mosaic on leaf & stunted height	Aphid, Seed & Mechanical	ssRNA	India, Pakistan Iran, Nepal, Bangladesh & Srilanka	Hussain and Abid, 2011; Sastry et al., 2019; Akhter et al., 2019
7	Pepper Veinal MottleVirus (PVMV)	Potyvirus	Potyviridae	Curling of leaf, Mosaic, Vein banding, Mottle, Leaf yellowing & stunted height	Aphid & Mechanical	ssRNA	India, Bangladesh, Nepal & Pakistant	Sharma et al., 2020; Myti et al., 2014; ; Paudel and Khanal, 2018
8	Beet Curl Top Virus (BCTV)	Curtovirus	Geminiviridae	Curling, Yellowing, Mosaic spot & Rolling of leaf, inter-veinal chlorosis & Stunted height	Leafhopper	ssDNA	Iran, Pakistan, Nepal, India & Srilanka	Eini et al., 2016; Hussain and Abid, 2011
9	Pepper mild mottle virus (PMMoV)	Tobamovirus	Virgaviridae	Mottling, Mosaic, Chlorosis, Stunted growth, Mottling, Puckering, Malformed leaves, small & deformed fruits	Aphid, Seed & Mechanical	ssRNA	India, Pakistan, Srilanka & Iran	Rialch et al., 2015; Ahmad et al., 2015; Alishri et al., 2013
10	Tomato mosaic virus (ToM V)	Tobamovirus	Virgaviridae	Mosaic mottling, Crinkling, curling of leaves & stunted growth	Aphid, Seed & Mechanical	ssRNA	India, Pakistan, Iran, Bhutan & Srilanka	Jamuna et al., 2018; Ullah et al., 2017; Lin et al., 2013

Chilly Leaf Curl Virus (ChiLCVD)

Chilly Leaf Curl Virus (ChiLCVD) is a member of the genus *Begomovirus* and family *Geminiviridae*. They are primarily found in the tropical and subtropical regions of the globe. *Geminiviruses* are recognized as one of the most destructive plant viruses in the world, causing a major threat to global food security [2,3]. South Asian countries, such as India, have also been listed [4,5]. It is also reported in Nepal and Pakistan, Bangladesh [6].

Yield loss: Yield losses caused by some *geminiviruses* have been estimated to be as high as 88-100% [7].

Symptoms: ChiLCVD symptoms include abaxial and adaxial curling of the leaves, puckering, and blistering of interveinous areas, thickening and swelling of the vein, and stunted growth [8,9]. Transmission of Leaf curl virus is reported by M. *persicae*, A. *nasturtii*, A. *craccivora*. *Bemisia tabaci* and *Bemisia gossypiperda* [10].

Resistant variety: The best resistant varieties reported are Pusa Jawala and Phule Jyoti.

Cucumber Mosaic Virus (CMV)

Cucumber Mosaic Virus (CMV) belongs to the genus *Cucumovirus* and family *Bromoviridae*. It occurs globally, mainly in temperate, tropic and sub-tropic regions of the world [11]. It has been found in India, Nepal, Sri Lanka, Bhutan, Pakistan, and Iran, and is one of the most widespread viruses in South-Asia [12,13]. CMV has affected over 1000 species in over 100 families, causing major economic losses in a variety of ornamental, horticultural, and vegetable crops. CMV disease incidence ranges from 46 to 47% in young plant stages [14].

Yield loss: CMV causes yield losses ranging from 20 to 100% and 10 to 20% even during harvesting time [15].

Symptoms: The Symptoms includes yellow moulting, distorted leaves, and stunted growth [16,17]. Mild mosaic and dull-coloured leaves, mottling, shoe-string, fern leaf, vein banding, vein clearing, leaf deformation, and stunted growth and decreased fruit size are the most common symptoms of naturally affected chilly plants [18].

Transmission: More than 80 species of aphids transmit CMV in a non-persistent manner; the most effective CMV transmitters are *Aphis gossypii* and *M. persicae* [19]. CMV is also transmitted by chilli seeds [20].

Resistant variety: CMV-resistant pepper genotypes have been reported. For example, genotype CA23 (Noakhali) is resistant to CMV in both natural and inoculated conditions, whereas genotype CA12 (Comilla-2) is moderately resistant [21].

Tobacco Mosaic Virus (TMV)

The Tobacco Mosaic Virus (TMV) is the first virus to be discovered. It belongs to the genus *Tobamovirus* and family *Virgaviridae* [22]. The virus was reported to infect the Chilly crop in India, Bangladesh, Pakistan, Nepal, Iran, Srilanka, and Bhutan [23,24].

Yield loss: The heavy yield losses due to this virus have been worldwide reported in tobacco, tomato, and pepper. The yield losses of up to 90% have been recorded in bell pepper because of TMV infection [25].

Symptoms: Infected pepper plants are usually stunted, deformed, with raised bumps and mottled areas in the leaves, as well as dark and light green areas [26]. Other symptoms include leaf mosaic, leaf curling, and stunted growth Fruit that has been infected shrinks dramatically in size and ripens unevenly [23,27].

Transmission: TMV is a seed-borne disease in chilly disease transmitted primarily by plant-to-seed communication, mechanical means such as hand, cutting tool, and other tools, but not by insect-vectors. TMV infects at least 125 different crop types, including tobacco, tomato, chilly, and cucumber [27].

Resistant variety: Pant C-1, Arka Harika, and Hisar Vijay are some of the TMV resistant varieties (Source: seednet.gov.in).

Tomato Spotted Wilt Virus (TSWV)

Tomato Spotted Wilt Virus (TSWV) is member of the genus *Tospovirus* and family *Bunyauitidae*. It occurs globally and mainly in temperate, tropic, and sub-tropic regions of the world [28,29]. Chilli has been identified to be infected by this virus in India, Pakistan, Nepal, Bangladesh, and Iran [24]. It can also be found in Asia and Europe [30].

Yield loss: TSWV reduced yield from 45% to 95% and in some cases up to 100%.

Symptoms: Mostly, infected chilly plant shows necrotic lesion or chlorotic spots, bronzing, curling, and wilting of leaves and necrotic streaks on the stem [31].

Transmission: Viruses are spread between plants in a variety of ways, including vegetative propagation, mechanical transmission by sap, seed, pollen, insects, mites, nematodes, dodder, and fungi. Thrips (*Frankliniella occidentalis*) transmit it [32]. Capsicum annum is a susceptible variety toward TSWV.

Resistant variety: TSWV resistant varieties include Capsicum chinense PI15225 and PI159236 [33].

Potato Virus Y (PVY)

Potato Virus Y (PVY) is a member of the genus *Potyvirus* and family *Potyviridae* [34]. PVY is most common in crops of the *Solanaceae* family, such as potato and chilli, and has a higher prevalence in pepper.

Yield loss: PVY Virus diseases resulted in yield losses ranging from 60 to 100%, and these were regarded as major constraints to the crop's economic production [35].

Symptoms: The symptom appeared in the naturally infected chilly plant were developed mild yellowing, vein clearing, vein banding, mottling, mosaic, and interveinal chlorosis in leaves and stunted hight.

Transmission: PVY is naturally transmitted by numerous species of aphid [36].

Resistant variety: PVY-resistant cultivars include Capsicum amaranticolor and Capsicum quinoa

Alfalfa Mosaic Virus (AMV)

Alfalfa Mosaic Virus (AMV), which belongs to the genus *Alfamovirus* and family *Bromoviridae* [37]. It infects over 400 plant species worldwide, including several vegetable and woody crops [38]. Although AMV is found all over the world, but in South Asia, it is most common in India, Iran, Bangladesh, and Pakistan [39]. In chilly fields, disease incidence ranged from 80 to 100%.

Symptoms: Common symptoms associated with AMV on pepper are blotchy white and bright yellow mosaic on its leaves [40]. Plants that are infected with the virus at a young stage display stunted growth with misshapen and blotchy fruits.

Transmission: AMV is the only one of these viruses that can be spread through pollen grains and seeds [41]. AMV has a broad host range and is spread by aphid species such as the Pea Aphid (*Acyrthosiphon pisum*) through mechanical and non-persistent transmission [42].

Resistant variety: As a result, resistant varieties such as Pusa Sadabahar, Arka Meghana, and Pusa Jawala must be used (Source: seednet.gov.in).

Pepper Veinal Mottle Virus (PVMV)

PVMV (Pepper Veinal Mottle Virus) belongs to the genus *Potyvirus* and the family *Potyviridae*. It is distributed worldwide [43].

Yield loss: PVMV causes yield losses ranging from 55 to 65% and disease incidents up to 100% in Nepal and other South Asian countries [44].

Symptoms: On infected chilly plants, PVMV causes curling, vein banding, mosaic, mottle, ringspot, leaf yellowing, blistering deformation, and plant stunting [45].

Transmission: PVMV is transmitted with aphid, the disease is usually transmitted by six species of aphids including (*Aphid creccivora, A. spiraecola, A. febae, A. gossypii, Myzus persicae and Rhapalosiphum maidis*).

But *Myzus persicae* and *A. gossypii* are most probably transmission vectors [46].

Resistant variety: The majority of chilly cultivars are susceptible to PVMV, except for NHV1-D96 and NHV1-E96, which are highly tolerant to PVMV infection [44].

Beet Curly Top Virus (BCTV)

Beet Curl Top Virus (BCTV) is a member of the *Curtovirus* genus and the *Geminiviridae* family. It is a virus that causes significant loss to the chilly, tomato, and sugar beet crops all over the world [47]. It is widely distributed throughout the Middle East and Africa, as well as in South Asian countries such as Iran, Pakistan, Nepal, and India [48].

Yield Loss: In the late 1900s, BCTV caused yield losses of up to 80% in southern New Mexico, as well as Iron, Pakistan, Nepal, and India in South Asia [48].

Symptoms: BCTV-infected chilly plant with curling, yellowing, mosaic spot, and leaf rolling, severe interveinal chlorosis, and internode shortening resulting in stunted height.

Transmission: *Circulifer tenellus* and *C. haematoceps* naturally transmit Beet Curl Top Viruses in a circulative persistent manner with a diverse host range of plants including beet, tomato, and chilly [49].

Resistant variety: BCTV resistant varieties include Pusa Jawala and Pant C-1 (Source: seednet.gov.in).

Pepper Mild Mottle Virus (PMMoV)

Pepper Mild Mottle Virus (PMMoV) is a single-stranded RNA virus that belongs to genus *Tobamovirus* and family *Virgaviridae* [50]. PMMoV is often distributing worldwide. It is found in South Asian countries such as India, Iran, Pakistan, Sri Lanka, and Bangladesh [51].

Yield loss: When a young plant becomes infected with this viral disease, it causes significant yield losses as well as significant damage to the quality of the fruits. Disease incidence ranges from 20 to 80%, with yield losses ranging from 50 to 100% [52].

Symptoms: Various symptoms have been associated with PMMoV disease elsewhere and include mottling, mosaic, chlorosis, stunted growth, mottling, puckering, malformed leaves, small and deformed fruits, [53].

Transmission: PMMoV is highly infectious, and it is spread in the fields by seed and soil, rather than insects [54]. PMMoV can survive on infected debris and in soil. It serves as primary inoculum for consequent crops [55]. Capsicum spp. is the virus's primary host, but studies have shown that it can infect up to 24 Solanaceae species as well as other *Chenopodiaceae, Cucurbitaceae, Labiatae*, and *Plantaginaceae* species.

Resistant variety: The susceptible variety is Kashi Shurkh (CCH-2) while the resistant varieties are Phule Jyoti, Pant C-1, and Pusa Jawala (Source: seednet.gov.in).

Tomato Mosaic Virus (ToMV)

Tomato Mosaic Virus (ToMV) is belongs to genus *Tobamovirus* and the family *Virgaviridae*. Genetic material is a positive, single-stranded RNA virus present with Road-shaped virion. ToMV has a worldwide distribution . In South Asian countries, it is found in India, Pakistan, Iran, Bangladesh, and Sri Lanka [56-59].

Yield loss: According to a survey conducted in two districts of Coimbatore, Tamil Nadu, India during March 2016 [60], disease incidence ranges from 15 to 20%, and it can cause yield loss ranging from 20 to 90% .

Symptoms: ToMV symptoms resemble those of TMV in most cases, with mosaic mottling, crinkling, curling of leaves, and stunted growth on pepper plants infected with ToMV [61,62]. It has been identified as infecting over 150 economically important crop species, including vegetables and ornamental flowers [37]. It is more common on tomato and pepper than TMV.

Transmission: Contact is the most common mode of transmission, but it can also be transmitted mechanically or by seed [25,63].

Resistant variety: Azad Mirch-1 is tolerant to (ToMV) but not resistant to it. Pant C-1 was thus used as a resistant cultivar (Source: seednet.gov.in)

DISCUSSION

We have listed all the top ten viruses of chilly in a table form which include their names, Genus, Family, symptoms, mode of transmission, Genotype, Country and references (Table 2). There are many other viruses reported in South-east Asia. Some of them are Chilly Veinal Mottle Virus (ChiVMV) and Tomato Yellow Leaf Curl Virus reported from Bangladesh, Tomato Leaf Curl Karnataka Virus (ToLCKV) and Tomato Leaf Curl New Delhi Virus (ToLCNDV) are reported in India [18,40]. Potato Virus X (PVX) and Tobacco Itch Virus (TIV) are reported in Sri-lanka as well as India [35]. The virus diseases in Chilly is a prevalent feature new species and strains of viruses are frequently being discovered, causing damage to the cultivar.

CONCLUSION

In this review we have discussed top 10 viruses that infect chilly crop in South Asian countries, it has been noticed that Chilly Leaf Curl Virus Disease (ChiLCVD), Potato Virus Y (PVY), and Cucumber Mosaic Virus (CMV) are most harmful and widespread. In our survey we found that India Pakistan, Bangladesh, and Iran have significant research work done while no virus-related work on chilly has been reported in Afghanistan and Maldives. Knowledge of different types of viruses infecting chilly crop may provide us basis to develop resistant varieties. Although many research works have been conducted on virus infecting chilly but still there are gaps to be filled in term of management of viruses.

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