Medical and Life Sciences (2024) 3(2): 46–53
ISSN (E): 2976-7245

Overview on Prevalence, Molecular Detection, and Phylogenetic Analysis of CMV Infecting Eggplant in Pakistan

Sonum Bashir[1]*
Sadia Basheer[2]
Muhammad Awais Fareed[1]
Rida Fatima[3]
Iram Bilqees[1]
Muti Ur Rehman[4]
Muhammad Usman Ghani[5]
Waqas Raza[6]
Judith J. Kiptoo[7]

How to cite this article:

Bashir, S., Basheer, S., Fareed, M. A., Fatima, R., Bilqees, I., Rehman, M. U., Ghani, M. U., Raza, W., & Kiptoo, J. J. (2024). Overview on prevalence, molecular detection, and phylogenetic analysis of CMV infecting eggplant in Pakistan. *Medical and Life Sciences, 3*(2), 46–53.

Received: 8 August 2024 / Accepted: 7 November 2024 / Published Online: 30 December 2024

Abstract

Eggplant (*Solanum melongena L.*) is a vegetable crop that has significant economic value and is widely grown in tropical and subtropical areas. Nonetheless, it is highly unproductive due to the prevalence of many viral diseases, especially RNA viruses such as Cucumber mosaic virus (CMV). The current research aims to identify, characterize and examine the genetic diversification of RNA viruses in eggplant in the Pothowar area of Pakistan. Field surveys were done, and symptomatic samples were examined by serological (DAS-ELISA) and molecular (RT-PCR) methods. The findings confirmed the prevalence of CMV and indicated a high disease incidence in the surveyed districts. Sequencing of the coat protein genes showed a high genetic diversity among isolates. Phylogenetic analysis showed that the local isolate formed a distinct cluster, indicating evolutionary separation. The paper discusses the relevance of early diagnosis and molecular profiling for the successful management of the disease and provides background for further research on virus resistance and control measures.

Keywords: Detection Techniques, Virus identification, Molecular and Genetic characterization, Epidemiology & Transmission

1 Introduction

Eggplant (*Solanum melongena L.*) is a vegetable crop that belongs to the Solanaceae family and is one of the most popular vegetable crops in the world because of its nutritional and economic

[1]Department of Plant Pathology, College of Agriculture, University of Sargodha, Sargodha-48100, Pakistan
Correspondence author: sonumbashir@gmail.com
[2]Department of Plant Pathology, University of Agriculture, Faisalabad, Pakistan
[3]Food and Agriculture Organization of United Nation, Khanewal-58150, Pakistan
[4]Institute of Chemistry, The Islamia University of Bahawalpur, Bahawalpur-63100, Pakistan
[5]University of Agriculture, Faisalabad, Sub-Campus, Burewala, Pakistan
[6]International Potato Center, China Center for Asia Pacific (CIP-CCCAP), Beijing-100021, P. R. China
[7]School of Biological and Physical Sciences, University of Nairobi, Nairobi, Kenya

Copyright (c) 2024 Author(s)
This work is licensed under a Creative Commons Attribution 4.0 International License.

importance (Taher et al., 2017). It is a source of essential nutrients, such as vitamins, minerals and antioxidants and a significant ingredient in diets in most countries (Gürbüz et al., 2018; Palukaitis et al., 1992). Although it is important, eggplant production is severely limited by several biotic stresses, with viral diseases being the most devastating. Eggplant is infected by a wide variety of viruses, of which RNA viruses are the most common: Cucumber mosaic virus (CMV), Tobacco mosaic virus (TMV), and Potato virus Y (PVY), leading to symptoms such as mosaic patterns, chlorosis, leaf distortion, and stunted growth (Mochizuki & Ohki, 2012). The infections cause significant yield and quality losses, posing a significant risk to sustainable agriculture (Francki et al., 1979). The CMV is one of the most prevalent and economically significant viruses because of its broad host range and its ability to be transmitted by aphid vectors. To devise effective control measures, it is important to understand the distribution, molecular features, and genetic diversity of these viruses (Rubio et al., 2020). Thus, the present research will help determine key RNA viruses affecting eggplant, describe them at the molecular level, and evaluate their phylogenetic patterns to better understand their evolution and transmission (Aubriot & Daunay, 2019).

2 Viral Disease of Solanaceous

Solanum melongena L., also known as aubergine, is an important solanaceous plant and is extensively cultivated in South Asia (Bangladesh, India and Pakistan), accounting for about 50% of the region's eggplant production (Rubio et al., 2020). All seasonal, mature and semi-perennial vegetables, such as eggplant, are available year-round. It has high nutritive value and contains all the essential minerals, vitamins and amino acids. In Pakistan, eggplant is cultivated on a large scale, but it lags behind many other countries in productivity. In eggplant, viral diseases are of great significance, as they affect agricultural production, food security and wages, particularly in tropical regions worldwide (Tolin & Fayad, 2016).

2.1.1 Cucumber Mosaic Virus (CMV):

Francki et al. (1979) reported that CMV (Cucumber mosaic virus) belongs to the Genus Cucumovirus within the family Bromoviridae. It is fiscally essential because it can infect a wide range of plant species and has a unique host range among all plant infections reported to date. CMV exists in different strains that differ in their hosts, indications, methods of transmission and other properties. The virus load increases for a few days after vaccination, then decreases until the plant dies. Smith et al. (2000) stated that Cucumoviruses comprise icosahedral particles with a diameter of 29 nm and approximately 180 capsid protein subunits. CMV has a molecular weight range of 5.8 to 6.7 million, with 18% RNA and 82% protein (Francki & Hatta, 1980). RNA is enveloped by a protein capsid, leaving an empty centre approximately 110 Å in diameter. Raj et al. (2005) demonstrated that CMV causes various symptoms and imposes significant losses on a few economically important vegetable crops. CMV sometimes causes infection at immature stages and produces mosaic in solanaceous plants. In eggplant, the virus causes a yellow mosaic, reduced plant development and reduced yield. Infected fruits are usually smaller and malformed, with yellow-white streaks (Tsitsigiannis, 2008). Kavyashri et al. (2016) reported that CMV is among the most widespread plant viruses worldwide. Hsu et al. (2000) showed that viral infection is not restricted to the yield plant; weeds have likewise been considered a refuge for virus inoculum, facilitating the further development of disease epidemics in nearby economic crop lands. Transmission of the virus through plant parts is also imperative in some plants and weeds. Palukaitis et al. (1992) described CMV as possessing a divergent host and causing disease in a lot of vegetables, ornamentals, and other plants, with 1191 host species belonging to forty families. Narayanasamy et al. (2011) evaluated that the virus is sap-transmissible. Virus is also transmitted by seed, though to a lesser degree. Hosts of the eggplant virus include *N. tabacum*, *Cucumis sativas*, *C. anguria*, *C. melo*, *Cucurbita moschata*, *C. maxima*, *C. pepo*, *Lagenaria siceraria*, *Trichosanthes anguina*, *Luffa acutangula*, *Luffa cylindrica*, *Momordica charantia*, *Citrullus vulgaris*, *Gomphrena globosa*, *Zinnia elegans*, *Brassica campestris* and *Hesperis matronalis*.

However, these are symptomless carriers. Plant viruses rely on vectors for transmission, and CMV is spread non-persistently by more than 75 aphid species (Shah et al., 2008). CMV is transmitted to 1287 plant species with cucurbits, solanaceous crops, cereals, fruits, vegetables, ornamental plants and also some new crops viz., tomato, pepper, cucumber, melons, squash, spinach, celery, beets, petunia, chickweed, mustard, sowthistle, nightshade, Musa spp. and several weeds are also hosts of CMV. According to Kumar et al. (2014), Cucumber mosaic virus (CMV) was originally identified in severe mosaic disease of eggplant isolates from Lucknow and Kanpur, India, by host reaction and serological assays, and by RT-PCR using coat protein gene-specific primers. Molecular identification of the virus isolates was complete by cloning and sequence analysis of the full RNA3 genome. 97–99% of the characteristics and phylogenetic relationships, the virus isolates that cause disease in eggplant were known to be members of CMV subgroup IB. As illustrated in Figure 1, Cucumber mosaic virus (CMV) is one of the most widely distributed and economically significant plant viruses infecting a broad range of host species. The virus possesses an icosahedral particle structure with a single-stranded RNA genome enclosed in a protein capsid. CMV is primarily transmitted by aphids in a non-persistent manner, although sap, seed, and infected plant materials also contribute to disease dissemination. In eggplant, CMV infection causes characteristic symptoms including mosaic, chlorosis, leaf distortion, stunted growth, fruit malformation, and yield reduction. The disease cycle involves virus survival in weed reservoirs, acquisition by aphid vectors, transmission to healthy plants, and subsequent spread under favourable environmental conditions.

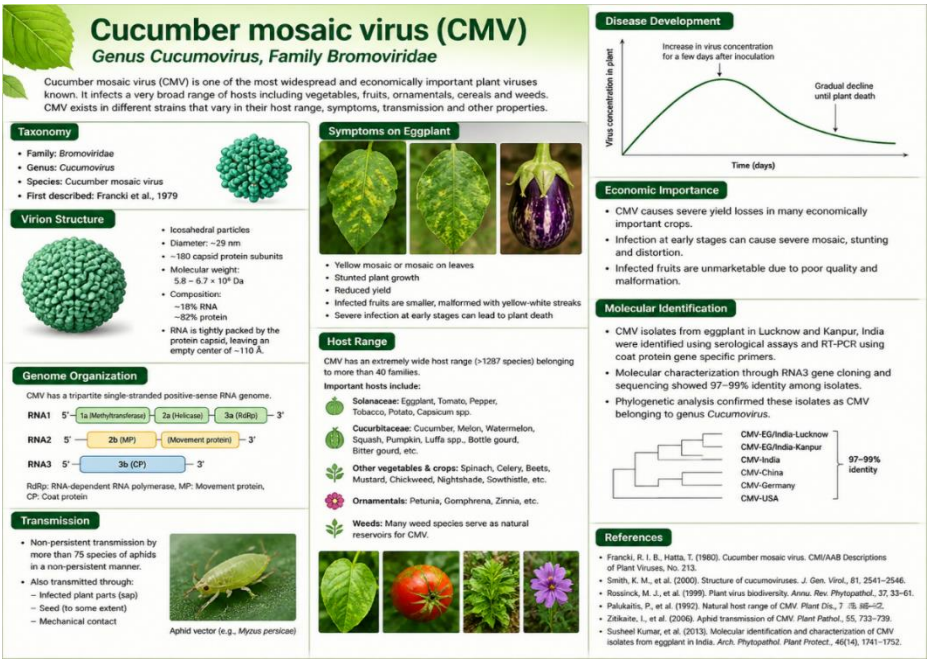

Figure 1. Schematic representation of Cucumber mosaic virus (CMV) showing its virus structure, transmission pathways, host range, disease symptoms, and disease cycle in eggplant and other susceptible crops. CMV is an economically important plant virus belonging to the genus *Cucumovirus* and family *Bromoviridae*, transmitted mainly by aphids in a non-persistent manner and infecting a wide range of vegetable, ornamental, and weed hosts.

2.2.2 Potato Virus Y(PVY):

Potato virus Y is a member of the genus Potyvirus in the family Potyviridae that infects eggplant

(Bhoi et al., 2022). It occurs globally and appears to be more important in temperate zones. Incidence can reach 100% in some regions. Mosaic, mottle, dark-green vein banding, vein clearing and yellowing are symptoms of PVY infection. PVY has a ss (+) RNA genome of about 10000 bp (Barker et al., 2010). The 5'-end of the viral genome is covalently linked to the viral protein genome-linked encoded protein (VPg). The 3'-end is organized by a poly-A sequence. A single Open Reading Frame (ORF) is extant on the PVY genome.

PVY can be transmitted by sap inoculation, grafting and by aphids. PVY is transmitted in a non-persistent manner. PVY is spread by 60 aphid species. PVY contains flexuous particles of 760 NM in length. It infects many crop species in the Solanaceae family, including potato, tomato (*S. Lycopersicum Mill*.), tobacco (*Nicotiana* sp.) and pepper (*Capsicum annuum L*.) (Motti, 2021). Its host range also includes non-solanaceous *Amaranthaceae*, *Leguminosae*, *Chenopodiaceae* and *Compositae*. Al-Ani et al. (2011) reported that PVY spread cannot be limited by aphicides because the period during which the virus spreads is too short for aphicides to kill the vector. Fine-mesh screens at entrances and gaps are a consistent practice for glasshouse crops. This exercise produces a significant decay in the problem by evading the first crop infection. Control of pests by disturbing their environmental status, as done with the use of biocontrol agents.

2.2.3 Eggplant mottled dwarf virus (EMDV):

Eggplant mottled dwarf virus (EMDV) is a distinct species of the genus Nucleorhabdovirus in the family Rhabdoviridae (Tang et al., 2015). After the first identification of eggplant (Solanum melongena) from southern Italy in 1969. EMDV genome is composed of a linear, single-stranded and negative-sense molecule of RNA, contained in enveloped bacilliform particles of 220-232 × 66-72 nm. The virus is transmitted in nature by the natural hosts of EMDV, which also include honeysuckle, pelargonium and pittosporum (ornamentals) and Capparis spinosa, *Solanum nigrum* and *S. Sodomaeum* (wild species). EMDV was verified to be the causal agent of vein yellowing disease in the China rose (*Hibiscus rosa-sinensis L*.). Parrella et al. (2013) reported that Eggplant mottled dwarf virus (EMDV) is also transmitted in nature by leafhoppers. The prevalence of infections is generally very low. EMDV has been demonstrated to be the causal agent of a vein yellowing disease of the China rose (*Hibiscus rosa-sinensis*) in southern Italy. In Iran, EMDV was identified first in potato, in which it caused chlorotic stunt. Incidence rates of up to 35% have been reported in eggplant fields in Shahrekord, central Iran. The most frequently used serological identification methods are agar gel immunodiffusion tests and immunoelectron microscopy. ELISA has been used to detect the hibiscus isolate of the virus.

2.2.4 Tomato Chlorosis Virus (ToCV):

Tomato chlorosis virus belongs to the Genus Crinivirus, family Closteroviridae. They possess a bipartite, positive-sense, ssRNA genome encapsidated in long filamentous virions approximately 800-850nm (Shakeel et al., 2017). RNA1 encodes proteins involved in replication, whereas RNA2 encodes up to 10 proteins involved in encapsidation, vector spread and cell-to-cell movement. Transmission is carried out exclusively through whitefly species that fit into the genus Trialeurodes and Bemisia. Transmission efficiency of ToCV varies between whitefly biotypes *T. abutilonea* and B. tabaci biotype B (MEAM1), with the latter being the most efficient vector (Wintermantel et al., 2006). ToCV is more widespread, having been reported in Europe, the USA, Brazil, Saudi Arabia, Jordan and China (Fiallo-Olivé & Navas-Castillo, 2019; Shakeel et al., 2017). ToCV has a wide host range, including lettuce, potato, pepper, and tobacco, and causes "yellow leaf disorder" in tomato plants, resulting in severe damage to the plant. It has also been reported to infect some cultivars of pepper.

Observed eggplant yellowing and interveinal chlorosis on the leaves of eggplants grown under greenhouse conditions in Haidian District, Beijing. Mature leaves showed more intense interveinal chlorosis than young leaves, and the percentage of plants exhibiting symptoms was 80%. A dense population of vector whiteflies was also observed in the greenhouse, suggesting the potential for

Tomato chlorosis virus infection. First report of S. melongena and S. Aethiopicum as natural hosts of ToCV; they can serve as sources of inoculum for the tomato crop in which ToCV. checked the infection of Tomato chlorosis virus (ToCV), Tomato infectious chlorosis virus (TICV) by RT-PCR assays using the primer pair HS-11/HS-12. Tomato chlorosis virus (ToCV) is an economically important plant virus associated with chlorosis and yellow leaf disorder in tomato and other solanaceous crops. The virus belongs to the genus *Crinivirus*, family *Closteroviridae* and is transmitted primarily by whitefly vectors. Its broad host range, efficient vector transmission, and global distribution make ToCV a significant threat to vegetable production systems. The major biological and epidemiological characteristics of ToCV are summarised in Table 1.

Table 1: Summary of important biological and epidemiological characteristics of Tomato chlorosis virus (ToCV)

Parameter	Description
Virus Name	Tomato chlorosis virus (ToCV)
Possible Genus	Crinivirus
Family	Closteroviridae
Genome Type	Bipartite, positive-sense single-stranded RNA (ssRNA)
Virion Morphology	Long filamentous particles
Virion Size	Approximately 800–850 nm
RNA Components	RNA1 (replication proteins), RNA2 (encapsidation, movement, vector transmission proteins)
Primary Vectors	Whiteflies
Vector Species	Trialeurodes abutilonea, Bemisia tabaci (MEAM1/B biotype)
Mode of Transmission	Whitefly-mediated transmission
Major Hosts	Tomato, eggplant, lettuce, potato, pepper, tobacco
Symptoms in Eggplant	Yellowing, interveinal chlorosis, leaf chlorosis
Symptoms in Tomato	Yellow leaf disorder, chlorosis, reduced vigour
Detection Method	RT-PCR using primer pair HS-11/HS-12
Reported Regions	Europe, USA, Brazil, Saudi Arabia, Jordan, China

2.2.5 Mosaic Disease of Eggplant (Possible Tymovirus)

Mosaic disease of eggplant is common in fields of southern Iran. A virus isolated from diseased samples of eggplants in the Boushehr Province (Sadeghi et al., 2008). The virus was mechanically infectious to Nicotiana tabacum cv. other solanaceous species. Two aphid species, *Myzus persicae* and *Aphis gossypii*, spread the virus. An antiserum raised against a purified virus preparation was used to recognise the virus. Sadeghi et al. (2008) reported that Mosaic disease of eggplant may be caused by viruses from the Tymovirus, Potyvirus, Cucumovirus, Tobamovirus and Carlavirus genera. Amongst potyviruses, Tobacco etch virus (PVY), Pepper veinal mottle virus, Brinjal mild mosaic virus, Eggplant green mosaic virus and Eggplant severe mottle virus are stated to infect eggplant. This disease is transmitted by *Aphis gossypii* and *Myzus persicae*. The disease symptoms include mosaic mottling and stunting of eggplants. The leaves of infested plants are deformed, small and leathery. Early stages of the contaminated plants show stunting growth. There are several viruses which 30 can infect brinjal under natural conditions and produce mosaic symptoms. Molecular weights of the virus genome and (CP) were expected at 3.1–3.2×106 and 36×103 Da. The 3 regions of the virus genome, with CP and (UTR), were improved using two pairs of primers. Eggplant mosaic virus (EMV) in eggplants was first reported from western India by Al-Ani and Adhab (2020). The virus is transmitted by sap, flea beetles (*Epitrix fuscula*), and aphids (*M. persicae*) in a non–persistent manner. EMV contains spherical particles of 28-30 nm in diameter.

2.2.6. Tobacco Mosaic Virus (TMV):

Tobacco mosaic virus (TMV) appear as mottling, malformation, threading, curling, bleaching

of the veins Tobacco mosaic virus (TMV) has been chosen as the important plant virus in the plant virology Tobamovirus are considered by a typical rod-shaped particle morphology encapsulating a single stranded RNA (+ssRNA) sense genome of 6.2 to 6.4kb encoding four ORFs Tobamoviruses are transmitted by mechanical interaction through workers' hands, clothes, tools, and are accomplished to preserve infectivity in seeds and contaminated soil. The family Tombusviridae includes a broad range of soil-borne viruses

2.2.7. Eggplant Blister Mottled Virus (EBMV) :

Eggplant blister mottled virus (EBMV) is a new virus, and a member of the potyvirus genus, also considered for the first time from Iraq. A new virus, Eggplant blister mottled virus (EBMV), was isolated from naturally infected Eggplant cultivation (Al-Anni et al., 2011). Potyvirus, based on its flexuous particle morphology of 720 nm in length in Iraq. EBMV is considered the most important virus of eggplant, causing significant yield losses. The virus is transmitted mechanically from diseased to vigorous plants via plant sap and by the vector *Myzus persicae* in a non-persistent manner. Symptoms considered leaf mottling, severe curling, blistering and stunting were established on eggplants.

2.2.8. Eggplant Mottled Crinkle Virus (EMCV):

A new viral disease, eggplant mottled crinkle virus (EMCV), causes a disease in the brinjal field in Israel, which causes major damage because of plant stunting, leaf mottling and narrowing (Dombrovsky et al., 2009). Virus purification from infected plants isometric particles are 37–40nm in diameter. Molecular characterisation of the viral agent specifies that it is an innovative strain of the Eggplant mottled crinkle virus (EMCV-Is) that has been allocated to the Tombusvirus genus. Phylogenetic analysis identified a relationship of EMCV with Pear latent virus (PeLV) and Lisianthus necrosis virus (LNV)**.** Epidemic of a new disease observed on brinjal grown in a field near Rehovot, Israel. Disease prevalence extended to approximately 100%. The causing injury was heavy, due to plant stunting attended by leaf and fruit malformation. The virus was firstly defined in Lebanon then in India and lately in Iran. Disease symptoms appeared as small chlorotic spots on leaves, then altered into rings and necrotic spots. Sap was removed from infected leaves in 0·1 M potassium phosphate buffer, pH 7, and mechanically inoculated on experimental plants. Geranium leaves with warning sign were also used for electron microscopy and total RNA extraction. RT-PCR amplification was performed using a primer pair designed from sequences flanking the coat protein (CP) gene of Pear latent virus (PeLV).

3 Conclusion

The current research affirms that RNA viruses especially the Cucumber mosaic virus (CMV) is very prevalent in areas where eggplant is grown in the Pothowar region and have a major role in reducing yields. Serological and molecular diagnostic methods were effective in the accurate diagnosis and confirmation of viral infections. Molecular characterization and phylogenetic analysis of the coat protein gene indicated that there was a great genetic variation in CMV isolates. The local isolate was a clear phylogenetic group, implying that it had evolved differently as compared to other isolates across the globe. This genetic diversity underlines the intricacy of the populations of viruses and the necessity of constant monitoring. On the whole, the results highlight the value of combining molecular instruments with conventional diagnostic applications to understand and manage the viral diseases in eggplant.

4 Future Aspects

It is recommended that future studies be conducted in order to create resistant eggplant varieties to viruses using the advanced breeding and biotechnological methods. Disease management strategies that are integrated, such as control of vectors, cultural practices, and resistant cultivars to reduce the spread of the virus also need to be explored. Future research and analysis with whole-

genome sequencing and enhanced molecular methods can offer more information on the evolution of the viruses, the diversity of different strains, and the interactions between hosts and viruses. Also, there is the need to have continuous surveillance and monitoring programs to help in identifying new viral strains and stopping massive outbreaks. Virus management in the cultivation of eggplants can be transformed using the modern tools like CRISPR-based resistance, RNA interference (RNAi), and prompt diagnostic kits. Intensification of awareness and extension services to farmers will also contribute to minimizing the effect of viral diseases on crop productivity.

5 References:

Al-Ani, R. A., & Adhab, M. A. (2020). Eggplant blister mottled virus (EBMV): A possible new potyvirus characterized from Iraq. *Advance Journal of Virology, Epidemic and Pandemic Diseases, 5*(1), 7–14.

Al-Ani, R. A., Adhab, M. A., & Ismail, K. A. (2011). Eggplant blister mottled virus (EBMV): A possible new potyvirus characterized from Iraq. *Journal of General and Molecular Virology, 3*(3), 49–54.

Aubriot, X., & Daunay, M.-C. (2019). Eggplants and relatives: From exploring their diversity and phylogenetic relationships to conservation challenges. In M. C. Daunay (Ed.), *The eggplant genome* (pp. 91–134). Springer International Publishing. https://doi.org/10.1007/978-3-319-99208-2_10

Barker, H., McGeachy, K. D., Toplak, N., Gruden, K., Žel, J., & Browning, I. (2009). Comparison of genome sequence of PVY isolates with biological properties. *American Journal of Potato Research, 86*(3), 227–238. https://doi.org/10.1007/s12230-009-9069-9

Bhoi, T. K., Samal, I., Majhi, P. K., Komal, J., Mahanta, D. K., Pradhan, A. K., … Ashwini, M. (2022). Insight into aphid-mediated *Potato virus Y* transmission: A molecular to bioinformatics perspective. *Frontiers in Microbiology, 13*, Article 1001454. https://doi.org/10.3389/fmicb.2022.1001454

Dombrovsky, A., Pearlsman, M., Lachman, O., & Antignus, Y. (2009). Characterization of a new strain of Eggplant mottled crinkle virus (EMCV) infecting eggplants in Israel. *Phytoparasitica, 37*(5), 477–483. https://doi.org/10.1007/s12600-009-0058-z

Fiallo-Olivé, E., & Navas-Castillo, J. (2019). Tomato chlorosis virus, an emergent plant virus still expanding its geographical and host ranges. *Molecular Plant Pathology, 20*(9), 1307–1320. https://doi.org/10.1111/mpp.12847

Francki, R. I. B., & Hatta, T. (1980). Cucumber mosaic virus—Variation and problems of identification. In *V International Symposium on Virus Diseases of Ornamental Plants* (Vol. 110, pp. 167–174). https://doi.org/10.17660/ActaHortic.1980.110.21

Francki, R. I. B., Mossop, D. W., & Hatta, T. (1979). *Cucumber mosaic virus*. CMI/AAB Descriptions of Plant Viruses, No. 213.

Gürbüz, N., Uluişik, S., Frary, A., Frary, A., & Doğanlar, S. (2018). Health benefits and bioactive compounds of eggplant. *Food Chemistry, 268*, 602–610. https://doi.org/10.1016/j.foodchem.2018.06.093

Hsu, H. T., Barzuna, L., Hsu, Y. H., Bliss, W., & Perry, K. L. (2000). Identification and subgrouping of cucumber mosaic virus with mouse monoclonal antibodies. *Phytopathology, 90*(6), 615–620. https://doi.org/10.1094/PHYTO.2000.90.6.615

Kavyashri, V. V., Pappachan, A., Padmaja, A. S., Nagaraju, N., & Rangaswamy, K. T. (2016). Biological and molecular characterization of cucumber mosaic virus isolate causing severe mosaic in gherkin (*Cucumis anguria* L.) in India. *Journal of Pure and Applied Microbiology, 10*(3), Article e48. https://doi.org/10.22207/JPAM.10.3.48

Kumar, S., Gautam, K. K., & Raj, S. K. (2014). Molecular identification of cucumber mosaic virus isolates of subgroup IB associated with mosaic disease of eggplant in India. *VirusDisease, 25*(1), 129–131. https://doi.org/10.1007/s13337-013-0174-8

Mochizuki, T., & Ohki, S.-T. (2012). Cucumber mosaic virus: Viral genes as virulence

determinants. *Molecular Plant Pathology, 13*(3), 217–225. https://doi.org/10.1111/j.1364-3703.2011.00749.x

Motti, R. (2021). The Solanaceae family: Botanical features and diversity. In S. M. Jain & H. S. Chawla (Eds.), *The wild solanums genomes* (pp. 1–9). Springer International Publishing. https://doi.org/10.1007/978-3-030-30343-3_1

Narayanasamy, P. (2011). Detection of virus and viroid pathogens in plants. In *Microbial plant pathogens: Detection and disease diagnosis* (pp. 7–220). Springer. https://doi.org/10.1007/978-90-481-9754-5_2

Palukaitis, P., Roossinck, M. J., Dietzgen, R. G., & Francki, R. I. B. (1992). Cucumber mosaic virus. In *Advances in Virus Research* (Vol. 41, pp. 281–348). Academic Press. https://doi.org/10.1016/S0065-3527(08)60039-1

Parrella, G., De Stradis, A., Greco, B., Villanueva, F., Fortes, I. M., & Navas-Castillo, J. (2013). First report of Eggplant mottled dwarf virus in China rose in southern Spain. *Spanish Journal of Agricultural Research, 11*(1), 204–207. https://doi.org/10.5424/sjar/2013111-3461

Raj, S. K., Srivastava, A., & Khan, M. S. (2005). Chimeric construction of expression vector of cucumber mosaic virus coat protein gene and tomato transformation. *Indian Journal of Virology, 16*(1–2), 69–69.

Rubio, L., Galipienso, L., & Ferriol, I. (2020). Detection of plant viruses and disease management: Relevance of genetic diversity and evolution. *Frontiers in Plant Science, 11*, Article 1092. https://doi.org/10.3389/fpls.2020.01092

Sadeghi, M. S., Behjatnia, S. A. A., Masumi, M., & Izadpanah, K. (2008). Characterisation of a strain of Potato virus Y causing eggplant mosaic in southern Iran. *Australasian Plant Pathology, 37*(1), 79–86. https://doi.org/10.1071/AP07087

Shah, H., Yasmin, T., Fahim, M., Hameed, S. H., & Haque, M. I. (2008). Transmission and host range studies of Pakistani isolate of chilli veinal mottle virus. *Pakistan Journal of Botany, 40*(6), 2669–2681.

Shakeel, M. T., Al-Saleh, M. A., Amer, M. A., Al-Shahwan, I. M., Umar, M., Dimou, N., … Katis, N. I. (2017). Molecular characterization and natural host range of tomato chlorosis virus in Saudi Arabia. *Journal of Plant Pathology, 99*(2), 415–421.

Smith, T. J., Chase, E., Schmidt, T., & Perry, K. L. (2000). Structure of cucumber mosaic virus and comparison to cowpea chlorotic mottle virus. *Journal of Virology, 74*(16), 7578–7586. https://doi.org/10.1128/JVI.74.16.7578-7586.2000

Taher, D., Solberg, S. Ø., Prohens, J., Chou, Y. Y., Rakha, M., & Wu, T.-H. (2017). World Vegetable Center eggplant collection: Origin, composition, seed dissemination and utilization in breeding. *Frontiers in Plant Science, 8*, Article 1484. https://doi.org/10.3389/fpls.2017.01484

Tang, J., Elliott, C., Ward, L. I., & Iqram, A. (2015). Identification of Eggplant mottled dwarf virus in *Hibiscus syriacus* plants imported from Australia. *Australasian Plant Disease Notes, 10*(1), Article 6. https://doi.org/10.1007/s13314-014-0153-y

Tolin, S. A., & Fayad, A. (2016). Virus diseases of tropical vegetable crops and their management. In K. P. Prabhakar & P. R. Peshin (Eds.), *Integrated pest management of tropical vegetable crops* (pp. 41–76). Springer Netherlands. https://doi.org/10.1007/978-94-024-0924-6_3

Tsitsigiannis, D. I., Antoniou, P. P., Tjamos, S. E., & Paplomatas, E. J. (2008). Major diseases of tomato, pepper and eggplant in greenhouses. *European Journal of Plant Science and Biotechnology, 2*(Special Issue 1), 106–124.