Potential insect vectors of plant virus diseases

Mayank Kumar and Bijendra Kumar

Every year, plants are affected by many diseases. Most of them are caused by fungi, bacteria and viruses. Among these causal organisms, viral diseases are difficult to control. Majority of plant viruses that cause disease in agricultural crops are transmitted by insect vectors (Whitfield et al., 2015). There are many classes of virus transmitting vectors like insects, mites, nematodes and chytrid fungi. Of these, insect vectors cause significant economic damage to crops. They transmit the virus in two modes *i.e.*, persistent or non-persistent manner. It depends upon the time window of acquisition and its further dissemination. Plant viruses usually rely on their vector for contravention the plant cell wall to be delivered directly into the cytosol. In most cases, there are specific viral capsid or membrane glycoproteins that are required for transmission and determinants of vector specificity (Whitfield and Rotenberg, 2015). Persistent viruses usually take long period of time up to virus life, while non-Persistent virus retained only for seconds to minutes in the insect stylets or foregut and released rapidly during salivation. Today about 94 per cent of animals that transmit plant viruses are arthropods. Of which insects especially whiteflies and aphids share 50%.

At present, the estimated potential yield losses caused by plant pathogens including fungi, bacteria, virus and nematodes is up to 16% globally. Virus disease pandemics and epidemics were estimated to have a global economic impact of >US$30 billion annually (Sastry and Zitter, 2014). Among the major virus diseases that causes high yield losses in different crops are belongs to tobamovirus, tospoviruses, begomoviruses, cucumoviruses, ilarvirus, potyviruses, tungro virus, carlavirus, babuvirus, badnavirus, polerovirus, and allexivirus (Scholthof et al., 2011; Sastry and Zitter, 2014; Mandal et al., 2017). However, the losses caused by plant viruses to agriculture crops may vary from crop to crop and sometimes from virus-to-virus species. At now most researches in plant pathology aims to reduce yield loss in our crops directly or indirectly. Losses by diseases not only affect farmers but also consumers because heavy infections lead to reduction in crop yields, leading to increase in the market prices.

At present there is no permanent solution for virus disease management. At now, they are just managing by some common prevalent techniques and methods like Quarantine, Host plant resistance, cultural and some others like chemical and biological control methods. The major target of these techniques like quarantine and cultural methods is to control the carrier of virus while other some aims to manage disease. Currently, it needs more careful studies on their mechanisms, host-vector specificity and genomic insight for successful management in agricultural crops.

No, Doubt, the largest class of virus-transmitting vectors of plants are insects but other vectors like mites, nematodes and chytrid fungi are also there. For the dissemination of 18 plant virus groups, there are 12 different groups of vectors. of these, 8 groups belong to insects like leafhoppers, treehoppers, plant hoppers, aphids, whiteflies, coccids, beetles and thrips. The major interactions by which these insects transmit the viruses are of four types (Whitfield et. al., 2015; Dietzgen et al., 2016).

a) Non-persistent transmission

Non-persistent viruses are usually retained in the distal tip of the insect stylet and transmit them through two strategies *i.e.*, either capsid-only or helper-dependent. In capsid-only, virion attached to the insect stylet and facilitated by a direct interaction, which is mediated by the capsid protein for example, cucumber mosaic virus (CMV) transmitted by the aphid Myzus persicae. In second strategy *i.e.,* helper-dependent, virion uses several or a single non-structural protein(s) (example potyviruses) for their attachment to the stylet.

b) Semi-persistent transmission non-circulative

These viruses usually retained by viruliferous vectors for longer period of time as compare to those which is transmitted in a non-persistent manner. These vector loose these viruses during molting. Semi-persistent

Table 1. Potential insect vectors of virus group by Bragard et al. (2013)

Vector Insect	Virus family	Virus Group
Leafhoppers	Reoviridae	Phytoreovirus
	Rhabdoviridae	Cytorhabdovirus, Nucleorhabdovirus
	Secoviridae	Waikavirus
	Tymoviridae	Marafivirus
	Geminiviridae	Mastrevirus, Curtovirus
	Caulimoviridae	Tungrovirus
Treehoppers	Geminiviridae	Topocuvirus
Aphids	Alphaflexiviridae	Potexvirus
	Betaflexiviridae	Carlavirus, Vitivirus
	Reoviridae	Raslavirus
	Rhabdoviridae	Nucleorhabdovirus
	Bromoviridae	Alfamovirus, Bromovirus, Cucumovirus
	Secoviridae	Fabavirus, sequivirus, Waikavirus
	Unassigned	Sobimovirus, Umbravirus
	Caulimoviridae	Badnavirus, Caulimovirus
	Closteroviridae	Closterovirus
	Luteoviridae	Enamovirus, Luetovirus,Polerovirus
	Nanoviridae	Babuvirus, Nanovirus
	Potyviridae	Maculavirus,potyvirus
Whiteflies	Betaflexviridae	Carlavirus,
	Secoviridae	Torradovirus
	Closteroviridae	Crinivirus
	Giminiviridae	Begomovirus
	Ophioviridae	Ipomovirus
Plant hoppers	Reoviridae	Fijivirus, Oryzavirus
	Rhabdoviridae	Nucleorhabdovirus, Cytorhabdovirus
	Unassigned	Tenuvirus
Coccids	Betaflexviridae	Vitivirus
	Caulimoviride	Badnavirus
	Closteroviridae	Ampelovirus
Thrips	Bromoviridae	Llarvirus
	Bunyaviridae	Tospovirus
	Tombusviridae	Machlomovirus
Beetles	Bromoviridae	Bromovirus
	Secoviridae	Comovirus
	Tombusviridae	Carmovirus, Machlomovirus
	Tymoviridae	Tymovirus
	Unassigned	Sobemovirus

viruses are internalized in the insect body by binding to chitin of the inner lining of the gut, but do not appear to enter in the tissues. Example: Crinivirus lettuce infectious yellows virus (LIYV), transmitted by whitefly (*Bemisia tabaci*).

c) Non-Propagative Transmission, Circulative

Usually, circulative viruses enter into the insect's body, prior to their transmission to plant and disseminate into the various tissue systems of insects. These virus are of two types i.e. that do not replicate inside insect body (Non-Propagative) while those which replicate inside insect body (Propagative) in different tissues. The entry of viruses inside insect body majorly described through salivary gland. Example: begomovirus by whitefly.

d) Propagative Transmission, Circulative

Circulative, propagative viruses are those viruses that replicate and systemically invade into the several organs and tissues of the vector insects. The primary goal of virus is to enter in the hemolymph or neuronal tissues of vectors in order to reach the salivary glands for transmission. Example; reovirus rice dwarf virus (RDV) in the leafhopper Nephotettix cincticeps.

Potential Insect Vectors

Insects have 29 orders, out of them, order Hemiptera is considered as the most potential group for virus transmitters in plants. However, few other vector species are found in six orders *i.e.*, Thysanoptera, Coleoptera, Orthoptera, Lepidoptera, Diptera and Dermaptera. At now, maximum insect vectors of plant pathogenic diseases are aphids, whiteflies, hoppers etc. (Table1). They have piercing and sucking mouthparts in common. Some most important vectors of plant diseases are described here (Fig 1).

1. Plant hoppers

They are the members of sub order Homoptera, which are distributed worldwide. All the members of this group are plant-feeders, surprisingly few are considered as pests which hamper economic important plants. At present there may be around 10,000 plant hopper species of which the most significant pest species occur within the Delphacidae family. Most of the disease vectors are found among delphacid plant hoppers. Recently the importance of plant diseases and their vectors have highlighted by the papers of Redak et al., (2004) and by Weintraub and Beanland (2006). At present, the potential plant hopper vectors of plant virus disease come under 4 families *i.e.,* Cixiidae (6 species), Delphicidae (4 species), Derbidae (1species) and Flatidae (1species).

2. Leafhoppers

At now, there are approximately 20,000 leaf hopper (Cicadellidae) species, which are already been documented and described but estimates suggest them over 100,000 species (Dietrich, 2005). Most of them belongs to Cicadellidae family under 10 subfamilies. For disease transmission, there are around 71species under these texa that responsible to transmit the viral disease. These vectors species comes under subfamilies Typhlocybinae (3), Scarinae (1), Macropsinae (5), Idiocerinae (2), Iassinae(1), Deltocephalinae (55), Coelidiinae (1), Cicadellinae (1), Aphrodinae (1) and Agalliinae(1).

3. Whitefly

Approximately out of 1,500 species of whiteflies (113), only few species have been shown to vector of plant viruses, and these vectors include the cotton/tobacco/ sweet potato whitefly [*B. tabaci* (Gennadius)] and the greenhouse whitefly (*T. vaporariorum* Westwood). By far the most important whitefly in terms of virus transmission is *B. tabaci*. It is typically polyphagous and generally found in tropical and semitropical regions. The main groups of viruses that are transmitted by whiteflies are begmovirus, ipomovirus, crinivirus carlavirus and torradovirus (Navas-Castillo et al., 2011). Some others like *Trialeurodes vaporariorum*, *T. abutiloneus*, and *T. ricini* (Misra) are also potential vector of many viral disease in plants. Recently, *Bemisia afer* sensu lato described as a vector of the crinivirus Sweet potato chlorotic stunt virus (Gamarra et. al., 2010). Generally, whiteflies transmit the virus in two modes *i.e.,* semipersistent and persistent. Semipersistent transmission requires minutes to hours for acquisition and has a retention time in the foregut of hours to days. In contrast, persistent transmission requires hours for acquisition, with a retention time in the haemolymph of days to the entire life of the insect.

4. Aphids

Aphids are the most common vector of plant viruses. The majority of aphid vectors belong to the subfamily aphidinae (Order: Homoptera) (Blackman and Eastop, 2000). Aphid vectors usually found in nine subfamilies, but they account for only a very small proportion of those that are known to transmit

Plant hopper

Leaf hopper

Whitefly

Aphids

Beetles

Fig. 1. Potential vectors of plant disease. Source: https://unsplash.com/s/photos

viruses. At present, aphids are globally distributed and there are more than 200 vector species of aphids have identified, a number that is most likely a gross underestimate (Nj and Perry 2004).

5. Beetles

Beetles are dominant group of insects. At present its 70 species are known to transmit virus diseases that infect economically important vegetables and grain crops. It is an estimated graph that beetles transmit approximately 11% of insect-borne viruses. Most of the beetle vectors of plant viruses belong to Chrysomelidae (flea beetle), Coccinellidae (coccid beetles), Curculionidae (weevils), Meloidae (blister beetles) families and have a unique mode of transmission. The virus group which usually transmitted by these beetles are belongs to six groups of plant virus genera: Machlomovirus, Bromovirus, Carmovirus, Comovirus, Sobemovirus, and Tymovirus (Wielkopolan et al., 2021)

6. Others

Some more insects like thrips, mealy bugs and coccids are their which spread the many economic virus disease to the plants. The major genus of thrips which spread the plant virus belongs to thrips, *Frankliniella*, *Scirtothrips*, and *Ceratothripoides*. The species that are known vectors of viruses are the members of Thripidae family with subfamily Thripinae. It included 1400 species in 230 genera. Plant viruses that transmit by thrips are Tospovirus, Ilarvirus, Carmovirus, Sobemovirus and Machlomovirus genera (Jones, 2005). Likewise, mealybugs that transmit viruses in semi-persistent manner are known to transmit some plant viruses that belongs to genera like *Ampelo*, *Badna* and *Clostero* genera . In case with scale insects and mealy bugs form the superfamily Coccoidea, contains arround 8000 species devided under 30 extant families. In those near about 35 species in the Coccoidea have so far been identified as vectors of 30 virus species, and classify majorly under two families *i.e.* Pseudococcidae (mealybugs) and the Coccidae (soft scales) (Herrbach et al., 2016).

Integrated Management

Presently, it is difficult to manage the plants infected with virus, unlike bacteria or fungi that can be treated with antibacterial or antifungal agents, respectively. So, viral disease management require some preventing measures like quarantine stations or some resistant plants from viral infection, using multiple strategies that must be developed specifically for respective virus, host, and environment. Some basic strategies for the management of vectors and its associated disease are described here as follow

1. Quarantine measures/Germ free planting

material

To stop the entry of any new microorganisms which is non-native, quarantine measures are must. Virus presence in quarantine can be check in the planting material by virus indexing. Many viruses are seed borne and carried by planting material. For them, certified seeds/planting material is necessary to check their initial build-up of infection in the field. So, it is recommended to always use virus free seed or the planting material so that there is no virus source available to the areal vectors to spread the pathogen. Once the source of getting virus is eliminated, the vector would not be able to receive the virus.

2. Host plant resistance (HPR)

HPR is the relative amount of heritable quality of plant which influences the ultimate degree of damage done by insects (Painter, 1951). For such situation resistant and tolerant verities is effective way of managing vectors and vector-transmitted diseases. It is one of the most important tactics by which the population of vector can be reduced on insect resistant cultivar and the pathogen resistant cultivar. Resistance to the pathogen may be the only means of management in some cases, example sugarcane mosaic virus. HPR has three components *i.e.,* antixenosis, antibiosis and non-preference. Non-preference should perhaps be the most effective form of resistance to the vector for control of non-persistent type viruses, whereas antibiosis may be effective for persistent types of viruses.

3. Cultural measures

In cultural management of virus, we may use some basic and effective management practices like isolation, alteration of in sowing and harvesting dates, modifying crop density and plant nutrition, destruction of vectors, barrier crops, traps, mulches etc. they all are useful, in virus vector disease management. Isolation is useful in to avoid the risk of viral infection. It is simplest and effective way of minimizing the number of viruliferous insects that can find the crop for multiplication and disease spread for example potato viruses. Next practices are alteration in sowing and harvesting dates. To avoid invasion of efficient vectors on crop, the sowing and harvesting dates are altered. In many parts of western countries, seed production of potato is found partly on prior haulm destruction before virus is brought into healthy crop by aphids. Another control measure is crop density and plant nutrition. It is practiced in tobacco leaf curl virus. It is more in robust crop when fertilized with excessive nitrogen. Similarly in the reduction of nitrogen dose in onion crop reduced the population of thrips and ultimately reduce vector population of viral disease. One important reservoir of viruses is the plants and weeds. So removal of these can minimize the initial inoculum. In annual crops alate vectors initiate/spread the virus and peak of virus spread coincide with peak of migrant alate vectors. They need to destroy at early stages especially for annual crops. Sticky traps are another way to reduce the vector population in field crops. They are working so well that they are now a standard practice for the control of potato viruses and cucumber mosaic viruses in many countries on various agricultural crops. The attraction of winged aphids to yellow has been utilized for many years in the yellow water pan traps or yellow sticky traps to monitor aphid populations. Sticky traps are used for direct vector control. This is a standard practice for the control of potato virus and CMV in peppers in Israel. Another effective method is by growing the crop under protected cultivation we can keep the vectors away from the crop. For example, covering tomato nursery with nylon nets for 3-4 weeks following by sprays of pesticide delayed the tomato leaf curl incidence for 3-5 weeks. Mulching of tomato and cucumber field with saw dust or yellow polythene sheets reduced the incidence of cucumber yellow vein virus and tomato yellow leaf curl virus and the population of the whitefly vector (Cohen and Melamad-Madjar, 1978). Combined use of mulching and pre-sprouting had a synergistic effect on reduction of PVY incidence (Doring et al., 2005).

Future and Conclusion

Vector-borne disease management represents some of the most economically important and invasive agriculture diseases. At present, many effective control strategies are used by the farmers to thwart the transmission of any insect-transmitted pathogen but most of them have negative impacts on the environment and human health and are unsustainable. Sustainable plant disease management specifically to vector born requires a multi-dimensional consideration for management approaches. Some of the key steps in their management are very important like correct identification. Due to genetic variation, identification is the major difficulty in their management. It can be solved by utilizing new techniques of identification like ELSA, LFA, and isothermal amplification (CRPA and LRMP). But management wants early detection. True detection always decides the management of any vector-borne disease. Systems biology could be another way to led the re-examination of existing paradigms on how pathogens interact with insect vectors, including the bacterial symbionts, and have identified vector-pathogen interactions at the molecular and cellular levels for the development of novel transmission interdiction strategies. Lastly, a brief overall summary is provided concerning how to achieve successful management of global virus disease pandemics and major epidemics that afflict important food crops. Currently, the available strategies that interfere with virus transmission by vectors include host genetic resistance to virus or insect, insecticides and integrated pest management. Finally, Better knowledge of these interactions and mechanisms of transmission will be essential for developing more effective control measures for a better future.

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AUTHORS

Mayank Kumar*
Department of Entomology
College of Agriculture
G.B. Pant University of Agriculture and Technology
Pantnagar, Uttarakhand India-263145

Bijendra Kumar
Department of Plant Pathology
College of Agriculture
G.B. Pant University of Agriculture and Technology
Pantnagar, Uttarakhand India-263145

*Email: mayankkumar1411@gmail.com