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Integrated Management of Insect Vectors of Plant Pathogens

Ravinder Singh Chandi

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ABSTRACT

A vector is an organism capable of transmitting pathogens from one host to another. Among the plant pathogen transmitting agencies, insect vectors are most important and various plant pathogens in crops are transmitted by insects. Insect vectors are much more hazardous because small population of vector can spread the pathogen in whole of the field or to new areas. These are difficult to manage and hence multi-pronged strategy should be adopted. To effectively manage insect vectors of plant pathogens there is a need to look into the careful timing of application of chemicals, integrated treatment with vector sampling, estimation of threshold level of vectors, assessing infection of pathogen at varying period of the year and combining insecticides with other means of control such as resistant cultivars, natural enemies, inclusion of plant products, cultural practices, biotechnology tools *etc*. An integration of control measures will be more effective and ecologically sound than any single method to control insect vectors of plant pathogens. The control of insect vectors with the use of various tactics should be used to reduce the severity and to delay appearance of disease.

Key words: Insect vectors, Management, Plant pathogens, Viruses.

Plants being immobile do not spread plant pathogens except through pollen, seed and human involvement. Therefore, the plant pathogens are dependent on various agencies for their spread and survival. Among the various plant pathogen transmitting factors, insect vectors are prominent ones. Vector is the most important component of virus disease epiphytology. A vector is an organism capable of transmitting pathogens from one host to another. An insect which acquires the disease causing organism by feeding on the diseased plant or by contact and transmit it to healthy plants is known as insect vector of plant diseases. There are species of insects known to act as vector of dreaded plant pathogens like viruses, bacteria, fungi, phytoplasma, rickettsia, nematodes and protozoa in crops. About 94 per cent of animals known to transmit plant viruses are arthropods. Most of the insect vectors belong to the order Hemiptera, Thysonaptera, Coleoptera, Orthoptera and Dermaptera. Among these Homopteran insects alone are known to transmit about 90 per cent of the plant diseases. The salient features of homopterans (aphids, leafhoppers) which make them efficient vectors are; they make brief but frequent probes with their mouthparts into host, as many species, winged females deposit a few progeny on many plants and these insects do not cause wholesome destruction of cells during feeding and viruses require living cells for their subsistence and multiplication. Insect vectors include mainly aphids, leafhoppers, whiteflies, thrips, psyllids, beetles, mealybugs *etc*. Plant pathogens are transmitted by a number of ways like by contact, by contamination through soil or other biological agencies. On the basis of the method of transmission and persistence in the vector, viruses may be classified into three categories *viz*. non-persistent, semi persistent and persistent viruses. Non-persistent viruses are also called stylet borne viruses. These are those viruses which are believed to be transmitted as contaminants of the mouthparts. The method of transmission

Department of Entomology, Punjab Agricultural University, Ludhiana-141 004, Punjab, India.

Corresponding Author: Ravinder Singh Chandi, Department of Entomology, Punjab Agricultural University, Ludhiana-141 004, Punjab, India. Email: rschandi@pau.edu

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of this kind of viruses is mechanical and these do not multiply in the vector. Semi-persistence viruses are carried in the anterior regions of the gut of a vector, where they may multiply to a certain extent. Vectors do not normally remain infective after a molt, presumably because the viruses are lost when the foregut intima is shed. Persistence viruses are those that persist longer within the infective agent. *i.e.* vector. These viruses, when acquired by a vector, pass through the midgut wall to the salivary glands from where they can infect new hosts. Such viruses may multiply within tissues of a vector, which retains the ability to transmit the virus for several days and in some instances, the rest of its life.

Irrespective of the type of transmission, virus-vector relationship is highly specific and spread of vector borne diseases also depends upon potential of vector to spread the disease. Also for transmission of virus, activity of insect vectors is more important rather than their number. The plant viruses can produce direct and plant mediated indirect effects on their insect vectors, modifying their behavior, fitness and life cycle (Delafuente *et al.,* 2013). There is a high degree of specificity of phytoplasma to insects and interaction between these two is complex and variable. A number of plant diseases caused by bacteria are known to be transmitted by insects because many of these insects are actually attracted by the sugars contained in the bacterial

exudates. Such bacteria are then likely to stick on the legs and bodies of insects and if the insects land on a fresh wound or on an open natural opening, the bacteria may multiply, move into the plant and begin a new infection. There are several insects associated with the spread of fungal diseases. The common sooty mold fungus grows on the honeydews excreted by several homopteran insects.

Insect vectors are much more dangerous and difficult to manage because small population of vector can spread the pathogen in whole of the field, particularly the plant viruses. Control options for insect vectors are quite different for vectors than insect pests because insecticide may increase rather than decrease the spread or incidence of virus diseases. Parasitoids, predators and pathogens seem neither as effective nor as promising for the control of vectors because economic threshold densities for vector species are much lower than those that would be expected to direct damage to the crop.

Management strategies for insect vectors

The interactions between vectors, plant pathogens and crops are not so simple. Many pathogens may be transmitted by more than one insect vector and on the contrary, there are some vector species that are able to transmit different plant pathogens. The knowledge about insect vectors is therefore crucial when deciding pest management strategies, especially on a wide scale area. Among the various types of plant diseases transmitted by insects, virus diseases are considered to be the most serious. Hence multi-pronged strategy needs to be adopted to manage the vectors and virus diseases. Some of the important components of such a strategy should involve selection of healthy seed, cultural practices, biological measures, resistant varieties and use of chemicals among others. Various strategies employed to prevent and reduce the intensity of plant viruses are discussed.

Quarantine measures and pathogen free seed/ planting material

These are imposed to prevent the entry of new pathogens from the area of its prevalence to the new area and are used to check the long distance spread of plant pathogens. Viruses are introduced into new areas through bud wood scions root stocks, trees, shrubs, tubers, rhizomes, corms, bulb, *etc*. of vegetatively cultivated plants. Tristeza virus was not present in countries like USA, China and South Africa which were cultivating citrus on large scale because of two reasons *viz*. resistant/tolerant varieties and absence of efficient vectors. The disease spread to South Africa in 1930 when susceptible root stock was imported. Certification schemes for potato have been introduced to produce virus (Potato leaf roll and PVY) free seed in many countries. Punjab is producing potato seed free of virus by following seed plot technique, taking into consideration the arrival of aphid vectors in state. To check the presence of virus in the planting material, virus indexing can be done.

Many viruses are seed borne and carried by planting material. The use of certified seeds/planting material is necessary to restrict the initial build-up of infection in the field. So always use virus free seed or the planting material so that there is no virus source available to the areal vector to spread the pathogen. Once the virus source is eliminated, the vector would not be able to acquire the virus. The yield of lettuce was increased in the Salinas valley area of California by cultivating the lettuce mosaic virus free seed (Kimble *et al.,* 1975). Cultivation of certified seeds always gives good dividends, such as seed certification schemes against BSMV have been credited with avoiding millions of dollars in losses due to this disease in barley crops in USA (Carrol, 1983). It can be achieved through different means like thermotherapy, chemotherapy, cryotherapy and electrotherapy. Besides, virus free plants through tissue culture technique can be produced.

Host plant resistance and paratransgenesis

Our ability to help growers to control vector-borne diseases depends on our ability to generate pathogen- and/or disease-resistant crops by traditional or synthetic approaches and to block pathogen transmission by insect vectors (Heck, 2018). Growing resistant and tolerant verities is another 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 will prevent the availability of virus sources from the field. To be successful, always depend on resistant varieties as it is cheap and most reliable measure. Resistance to the pathogen may be the only means of management in some cases. An example is sugarcane mosaic virus. 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. It is desirable to breed varieties resistance to vector. Resistant varieties are the most effective source of insect vector management which ultimately resist viruses. A sugarbeet germplasm line, CR09-1 resistant to beet necrotic yellow vein virus was developed and registered in USA (Lewellen, 2004). Genetically modified plants can be the best solution to tackle the problems of insect vectors of plant pathogens.

Paratransgenesis is a novel approach for genetic manipulation of host symbiotic microorganisms to achieve an array of objectives ranging from disease eradication to pest control. Such arthropods containing these transformed microorganisms are called paratransgenic. Genetic engineering of gut symbiont provides a new form of transgenic arthropod that has been termed paratransgenesis (Durvsula *et al.,* 1997). Genetic manipulation that can be cultured outside their host is easier to achieve than transformations of the arthropod itself. This novel approach has been exploited to modify infectious pathogen mediated diseases in pierce disease of grapes, Fiji leaf gall in sugarcane *etc*.

Cultural measures

These are most important measures used to tackle the problems of vector borne viruses. Insecticides seldom prevent viruliferous insect from spreading diseases, rather agro-techniques are much relied upon to avoid spread of pathogens. Only requirement is to efficiently select the measures and use them in proper sequence so as to minimize the damage. Several cultural practices have proved to be helpful in reducing the incidence of vectors and vector borne diseases. Many of the effective management practices for diseases caused by vectored plant pathogens involve some sort of cultural control such as adjusted planting date, pruning, rogueing and removal of volunteer crop plants and other non-crop reservoir hosts of vectors or pathogens. Other cultural control measures include elimination of weed hosts of vectors or pathogens, use of reflective mulches and paints to repel vectors and various protective row covers. Intercropping with a barrier crop has provided encouraging results to reduce the incidence of several diseases. Manipulation in planting dates is another way of reducing the disease incidence.

Isolation

Growing of virus susceptible crops in isolation is a useful practice to avoid the risk of viral infection. Increasing the distance between the virus source and crop may be simplest and effective way of minimizing the number of viruliferous insects that can find the crop. Therefore, efforts should be made to grow the crop in a site where the vectors are unable to infect the crop. So, minimum effective isolation distance can be estimated from quantification of disease gradient (Thresh, 1976). To protect the potato crop from potato viruses in India, the crop is grown in hilly areas where aphids are not present for most of the crop season. This technique is being followed to produce virus free (Potato virus X, Potato virus Y, Potato leaf roll virus) seed in potato.

Altering planting/harvesting dates

There are number of instances in which the time of planting or harvesting has been shown to influence the incidence of viral diseases. To avoid invasion of crop by efficient vectors, the sowing and harvesting dates are altered. In many parts of Europe and America, seed production of potato is based partly on early haulm destruction before virus is brought into healthy crop by aphids. In India, successful seed production was there in Shimla where aphid population was not there which could infect the tuber during the crop season. Seed plot technique is followed for raising potato seed crop in Punjab free from viral infection of potato leaf roll and other aphid borne viruses. Potato sowing in September and haulm cutting in December before the arrival of aphid vector is a practiced to get rid of tubers infected with potato viruses. Haulm cutting practiced after December in potato makes the tubers infected with potato viruses as a vector become abundant after December in plains of Punjab. Harpaz (1982) controlled the incidence of maize rough dwarf virus by altering the planting dates of maize in Israel. Late sowing (October instead of September) reduced the BYDV in cereals in Austria by discouraging the aphid population at that time.

Modifying crop density and plant nutrition

Brown plant hopper is more abundant when rice plants are closely spaced. This practice is being exploited to manage viral infection in rice by reducing vector. Adults of many aphid spp. seem to preferably exploit young plants spaced out and grown against bare soil as compared to close spaced plants. So increase in crop intensity may reduce aphid colonization. Reddy *et al.* (1983) observed early planting and increased plant density reduce the incidence of groundnut bud necrosis virus in groundnut. Plants possessing better growth with succulent foliage are preferred for feeding of insect vectors, thus likely to suffer more from viral infections. Infection of tobacco leaf curl virus is more in a robust crop when fertilized with excessive nitrogen. The reduction in the dose of nitrogen in onion crop reduced the population of thrips (Buckland *et al.,* 2013).

Destruction of host plants of vector

The plants and weed hosts are known to serve as reservoir for viruses and these plants become primary sources of infection. Vectors often breed on other crops or wild hosts that are also sources of virus. 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 vector. The epidemiology of such diseases depends upon time of peak of alate vector and stage of crop, the distance of crop from alternate host from which alate vectors are to be set off and the flight behaviour of the vector which leads them to find the crop plant. Groundnut mosaic virus is epidemic in some South African, the rouging of diseased plants from new planting sites after two months of planting resulted in control of virus. Banana bunchy top virus can be successfully controlled by rouging the diseased plants. The rogueing of diseased plants in cassava for cassava mosaic virus is being practiced regularly to mitigate the disease severity (Thresh and Cooter, 2005).

Mixed/barrier crops

Mixed crops are always helpful in preventing the secondary spread of vector borne pathogens. This practice is common in minimizing the incidence of non-persistent plant viruses. As the viruliferous vector particularly aphids when feed for little longer period on the non-host inter crop loose the virus. Intercropping of onion and garlic with tomato decreased the level of thrips infestation by 79-86 and 81-85 per cent, respectively (Afifi and Haydar, 1990). Barrier crops are likely to be more effective in protecting plants from non-persistent type around the main crop. Sunflower acts as barrier crop in tomato, celery against vein banding and potato virus Y. Further sunflower, sesame, pearl millet reduced the incidence of cucumber mosaic virus in chilli when used as barrier crop in Punjab (Deol and Rataul, 1978). By using barley as a barrier crop along with application of albolineum

oil give complete control of tulip breaking virus (Harrison *et al.,* 1976). Growing maize as barrier crop on borders and mulching with paddy straw reduced the incidence of mungbean yellow mosaic virus (Mukhopadhyay *et al.,* 1994). Maize and sorghum are grown as barrier crops in pepper for cucumber mosaic virus and potato virus Y in Spain (Fereres, 2000). Maize and wheat were used as barrier crop in potato to trap population of aphids for potato viruses in seed production plots in Africa (Schroder and Kruger, 2014). Incidence of yellow vein mosaic of okra is reduced by intercropping with soybean. Similarly, intercropping of tomato with coriander reduces the incidence of tomato leaf curl virus in tomato.

Breaking crop cycle

Control of tobacco leaf curl virus was obtained by keeping the field fallow for three weeks after the harvesting of tobacco crop. Whitefly vectors could not acquire the virus. The arthropods spread the virus from old to new crops and control is achieved by omitting a crop from cycle. Rice tungro virus is serious in South India where rice is grown after rice. The volunteer wheat provides a 'green bridge' for the viruses and their vectors between harvest of one crop and emergence of the next one (Halbert, 2011). To control these diseases crop rotations must be followed. Sugarbeet growers in California broke the infection cycle of virus yellows by introducing a beet free period in the field. During this period attention was given to prevent sugarbeets being left in the ground and cooperative efforts were made to destroy the weeds (Duffus, 1983). Wisler and Duffus (2000) introduced lettuce free and beet free periods to eliminate lettuce mosaic virus and beet western yellows virus in California along with resistant varieties. By establishing crop free period (mid-June to mid-July) in Arvara valley of Israel, the attacks of aphid and whitefly transmitted viruses in vegetables was reduced (Ucko *et al.,* 1998).

Use of sticky traps, protective cover and mulches

Sticky traps are working so well that they are now a standard practice for the control of potato viruses and cucumber mosaic viruses in Israel. 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. By growing the crop under protected cultivation we can keep the vectors away from the crop. By 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. Many crops are grown under green houses to control the vectors of pathogens. Enhanced management in flower bulb production is achieved through the use of reflective mulches in the virus control (Wilson, 1999). 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 Madjar, 1978). Combined use of mulching and pre-sprouting had a synergistic effect on reduction of PVY incidence (Saucke and Doring, 2005).

Chemical control

Chemicals are used against the vectors of plant pathogens to manage plant viruses since long. Understanding the transmission process and interaction between insects and their chemical environment elucidates areas of the epidemiological cycle at which pesticide oriented control strategies could be targeted most effectively. To apply this, it is always desirable to know the complete virus vector relationship indicating whether the virus is of non-circulative, or semi-persistent or persistent category. Perring *et al.* (1999) observed that of the reported successes controlling virus spread using insecticides, a high percentage (94 of 119 cases) were persistently and semi-persistently transmitted viruses.

The control of insect vectors by application of insecticides appears to be a difficult task as few survivors would be able to transmit the disease. The timely application of insecticides restricts the spread of the disease by reducing the vector population. Several systemic and non-systemic insecticides have been reported to control the insect vectors. Although different chemicals are readily availability, but use of insecticides is not a good idea as far as management of non-persistent category of plant viruses is concerned. The non-persistent and semi-persistent type viruses require short inoculation period. The use of insecticides will increase the incidence of viruses because of increased movement of vectors and increase in probing by disturbed and restless vectors of stylet borne viruses. Also these chemicals kill the natural enemies of vectors. As a result the population of vector will increase and will cause extensive damage. However, viruses of persistent (propagative) and semi-persistent (circulative) categories are effectively controlled with insecticides. Various chemicals can be used to manage insect vectors like chemicals of plant origin, antifeedants, repellents, pheromones, baits, mineral oils and insecticides. The use of biopestcides such as microbial and plant extracts is an eco-friendly approach to manage the vectors and vectors borne diseases. Many chemicals have been shown to reduce the rates of feeding, setting or reproduction of hemopterans eg. Dodeconoic acid and polygodia for *M. persicae* (Gibson *et al.,* 1982). Many pesticides of plant origin are used to control plant viruses. Azadirachtin is used to tackle Barley yellow dwarf virus transmitted by aphids (West and Mordue, 1992). Minerals oils are highly effective against non-persistent viruses as they cause physical blockage of air exchange and act as physiological poison, reduce probing/feeding of vector, alter vector behavior and locomotion, impede acquisition/infection process as they inhibit virus during probing through stylet contacts and may affect plant physiology and landing of vector (Fereres and Moreno, 2009).

It is possible to eliminate arthropod vectors or considerably decrease their numbers either with chemicals

or any other means. The threshold for vector is extremely low, in most cases single insect is sufficient to spread virus. In case of vectors where viruses persist throughout the life of vector, it becomes more cumbersome to manage such vectors.

Biological control

Sometimes natural enemies play good role in reducing numbers of harmful insects acting as vector of plant pathogens. Otherwise the natural enemies survive on insect host which means that insect population should be there for the survival of natural enemies. However low level of population of insect vector could prove harmful as only one individual is capable to spread the disease in the field. The maintenance of low population of insect vector could be dangerous. Biological control in simpler island ecosystems may have a better chance to work than in more complex settings. For example, the introduction of psyllid parasitoids into Reunion Island dramatically reduced the transmission of the bacteria that causes citrus greening disease. However, the same parasitoids are present in Vietnam, and citrus greening disease is a major limiting factor in citrus production there. *Encarsia formosa* is a parasitoid used worldwide for the biological control of whiteflies on vegetables and ornamental plants grown in greenhouses (Hoddle *et al.,* 1998).

Integrated pest management

For the management of various types of plant diseases transmitted by insects, integrated strategies should be adopted to manage the vectors. For any successful vector management programme, all the tactics should be combined carefully. For this strategy to be effective, identification of the plant pathogens and insect vectors is very important alongwith knowledge of their biology. Sampling methods and monitoring techniques should be developed to estimate abundance of insect and virus in relation to the phenology of the crop. The potential damage must be assessed by some appropriate method and it should be related to the number of vectors in the crop and to the proportion that are viruliferous. Predictive/ phonological and strategic models should be evolved. The successful use of viral capsid protein to deliver toxins to vectors and use of viral proteins to prevent transmission and entry to vectors can provide a platform for development of new control strategies for viruses and their vectors (Whitfield *et al.,* 2015). Stillson *et al*. 2020 advocated a decision support systems that integrated monitoring of aster leafhopper that vectors aster yellows phytoplasma with rapid disease diagnostics and web based text messaging in two crops, carrots and celery. Weintraub and Beanland (2006) suggested that genetic modifications which include enhancement of genes naturally present within the plant that code for defensive compounds or the introduction of alien genes into crop plants will provide protection from the vector insects.

In IPM strategies, efficient control will depend on sequence which has been chosen to manage plant viruses. IPM strategy was found effective by aphid control in Zucchini and ultimately checking the papaya ring spot virus in Australia (Pionese *et al.,* 1994). Culbreath *et al.* (2003) developed an integrated system for suppression of TOSPO virus in tomato by use of moderately resistant cultivar, cultural and chemical practices in combination to suppress the pathogen. Birch *et al.* (2004) used white sticky traps, specific flower volatile attractants, resistant verities, synergism with natural enemies and chemicals to control raspberry beetle.

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