Mite Transmission of Plant Diseases

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Abstract

Most plant viruses depend on vectors for their survival and spread. Mite-borne plant viruses may cause severe or even crippling losses to many annual and perennial crops in the tropics and semi-tropics which provide ideal conditions for the perpetuation of viruses and their vectors. Many worm mites (Eriophyidae), false spider mites (Tenuipalpidae) and spider mites (Tetranychidae) are known as vectors of virus diseases infecting cereals, fruit trees, pulse crops and coffee plants. Wheat streak mosaic virus (WSMV), wheat spot mosaic virus (WSPMV), ryegrass mosaic virus (RgMV), fig mosaic virus, cherry mottle leaf virus, current reversion disease, pigeon pea sterility mosaic disease and rose rosette diseases are all vectored by different species of eriophyid mites. Virus diseases like citrus leprosis and passion fruit green spot virus are vectored by false spider mites. Barley yellow streak mosaic virus (BaYSMV) is vectored by spider mite, *Petrobia latens*. Mango malformation disease (MMD) which was earlier reported associated with bud mite *Aceria mangiferae* is now found to be caused by fungal pathogen, *Fusarium moniliforme* var. *subglutinans*. Management of these diseases through genetic host resistance, adoption of cultural practices, chemical applications and various regulatory measures is suggested.

Keywords

Transmission • Viral diseases • Mango malformation • Monitoring

Most plant viruses depend on vectors for their survival and spread. Most vectors (insects and mites) have piercing mouthparts that transmit plant viruses in either the circulative virus (CV) or non-circulative virus (NCV). Non-circulative viruses are carried on the lining of the cuticle of vector stylets. CVs cross the vectors' gut, move internally in the salivary glands (SG) and cross the SG membranes to be ejected upon feeding. Most plant viruses depend on vectors for their survival because of the presence of an impermeable cuticle that coats the plant epidermis, preventing entry

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of virus particles. Many virus diseases may spread by contact or by vegetative reproduction. Hemipterous insects (including aphids and leafhoppers) are well adapted to their role as vectors by their capacity to pierce the epidermis and delicately deposit viruses in the cytoplasm without risking the integrity of the plant cell. Moreover, plants are rooted and lack independent mobility; therefore, many viruses depend on insects and mites for transport among hosts (Jeppson et al. 1975).

Progress in molecular biology of viruses and their vectors has assisted in identifying motifs in the viral genome, and in viral and vector proteins, thus adding to the understanding of the process of virus transmission of insects and mites. Depending on their period of retention of virus in their vectors, viruses are known as persistent, semi-persistent and non-persistent. Non-persistent viruses are generally known as stylet-borne, while persistent viruses are referred to as circulative. Non-persistent viruses are acquired and inoculated during brief probing times and do not require a latent period in the vector (as in aphids). Semi-persistent viruses need longer periods (hours) for acquisition and transmission than do non-persistent viruses; semi-persistent viruses have a narrow range of vector species. However, they too need no latent period and are lost when the vector moults. In persistent viruses, the longer the acquisition and inoculation times, the higher is the rate of transmission. They mostly have a narrow range of vectors, pass through moult and need a latent period.

Mite-borne plant viruses may cause severe or even crippling losses to many annual and perennial crops in the tropics and semi-tropics which provide ideal conditions for the perpetuation for viruses and their vectors. On occasions, mites are responsible for transition from a non-spreading form to the epidemic form of diseases. Many worm mites (Eriophyidae), false spider mites (Tenuipalpidae) and spider mites (Tetranychidae) – all possessing piercing and sucking mouthparts – are known as vectors of virus diseases infecting cereals, fruit trees, pigeon pea and coffee plants (Jeppson et al. 1975; Slykhuis 1969). The plant diseases both viral and fungal for which mites act as vectors are discussed below briefly.

16.1 Plant Viral Diseases Vectored by Eriophyid Mites

Eriophyid mites are very small (0.2 mm or 200 μm), four legged and worm type having piercing–sucking mouthparts. They usually feed on young tissues in buds or on leaves of their specific host plants. Some such mites cause leaf discolouration, malformation, galls, bud blasting, swelling and other varied symptoms because of their feeding, and these symptoms are often confused with symptoms caused by some viruses. Manual transmission, graft transmission, tests with non-viruliferous mites and the continued development of symptoms after the elimination of mites are commonly used as tests for establishing the role of mite vectors in transmission of different virus diseases.

16.1.1 Wheat Streak Mosaic Virus (WSMV)

Wheat streak mosaic virus (WSMV) is distributed widely in Australia, Canada, Mexico, Russia, the USA and some European countries. WSMV is a seed and mite-borne virus that infects wheat causing severe leaf symptoms and reduced yields (ER1 and ER2). The wheat curl mite (WCM), *Aceria tosichella*, vectors this virus. It completes its life cycle in 8–10 days and under ideal conditions a single female lays 12–20 eggs. Peak mite population is found at approximately 25 °C but its development is reduced at 30 °C and below 15 °C. WCM is capable of surviving for a few months in cold conditions but reproduction is significantly lowered (Slykhuis 1967). WCM reproduction is greatest following periods of rain and warm temperatures (25–28 °C).

WCM infestation generally causes little direct damage in the field other than the characteristic leaf curling and the occasional trapping of the flag leaf. However, both nymphs and adults of WCM transmit wheat streak mosaic virus (WSMV). For a mite to become viruliferous, the virus must be acquired during the two nymphal stages, typically after at least 15–30 min of feeding on infected plant material. Once infected the mite has the potential to transmit the virus to noninfected plants for at least 7 days.

Wheat is the primary host of WCM, but the mite has been recorded on more than 60 other plant species (including barley, oats, annual grass and many graminaceous weed plants). Infected volunteer wheat and alternate host plants provide both an effective 'green bridge' refuge for WCM outside the growing periods of wheat and serve as a potential sources of reinfestation and spread of WSMV to the successive wheat crops. WCM do not colonize on plants having broad leaves. WCM is mainly dispersed through wind. So WCM survival and dispersal are key factors influencing the spread of WSMV. In addition to WSMV, WCM has been implicated as the vector (carrier) of at least five viruses, namely, wheat spot mosaic virus, wheat spot chlorosis pathogen, cereal spotting, triticum mosaic virus and high plain virus. The same mite in earlier literature has been referred to as *Aceria tulipae*, which is actually more commonly found on liliaceous plants.

Early infection of wheat streak mosaic virus (WSMV) is responsible for the greatest loss of wheat yield. Plants infected between tillering and first node often do not set any seed, while those infected between first node and booting typically have reduced seed size. Infected seedlings often die prematurely, while later infection causes progressively less damage with only slight losses expected when infection occurs in spring growing periods. Serious outbreaks of WSMV can only occur if the virus is present and WCM is abundant.

Plants with low levels of infection may show minor or no visual symptoms. But plants infected with WSMV are typically characterized by leaf mottling and streaking. Light green streaks running parallel to the leaf veins are the first signs of WSMV infection. As the disease becomes more established, the streaks turn yellow and develop into blotches, giving the leaf a green and yellow mosaiclike pattern. Tillers on affected plants tend to be less erect than those on uninfected plants. Affected plants can die prematurely or fail to grow, becoming stunted relative to healthy plants. Heads on infected plants can be sterile and contain no seed or can have small or shrivelled grains. Affected plants often occur in patches or at crop boundaries closest to grasses that were growing when the crop emerged. Stunting symptoms are much less obvious with late infection. Symptoms of WSMV typically develop at temperatures above 10 °C, so they are masked during winter. WSMV can cause crop failure in wheat when widespread infection occurs at the seedling growth stage.

WSMV is seed-borne at low levels (less than 1 %) in wheat seed. Transmission through the seed has the potential to cause significant yield losses because of early appearance of WSMV in wheat crop. Early widespread infection of young wheat plants (approaching 100 % infection) is generally associated with greatest yield losses from WSMV and can cause complete crop failure, as such crops produce only small amounts of shrivelled grains. However, minimal yield loss occurs when wheat crop becomes infected post-tillering.

Management Serious outbreaks of WSMV can only occur if the mite vector (WCM) is abundant and a source of WSMV is present. So the management of the disease is highly dependent on controlling WCM populations and sources of WSMV. Following control options against WSMV should be followed:

- Control the 'green bridge' (volunteer crop cereals, e.g. wheat, barley, cereal rye, oats and grassy weeds) as these hosts harbour both WSMV and WCM. So their control needs to be done throughout the paddock (including along the fence line) at least one month before sowing wheat.
- Sow healthy seed stocks of wheat.
- Avoid early sowing in virus risk conditions.
- Break the disease cycle by controlling over-summering volunteer wheat/cereals and grasses within the field, on field boundaries and road sides, reducing the mite populations invading autumn sown crops.
- Whenever it is possible, delay sowing of wheat in autumn until temperatures are too low for mite activity.

Acaricidal control of mites is believed to be largely ineffective as WCM predominantly lives protected within the leaf whorls and is difficult to target and does not respond well to the pesticides. Moreover, WCM lacks a diapause, an over-summering egg stage that many mite species have. Eggs must die off or hatch to continue development on alternate host plants and volunteer wheat. Even the herbicides like glyphosate require up to 4 weeks to achieve full plant mortality, and in the meantime dispersal of WCM through wind may occur on a new host.

16.1.2 Wheat Spot Mosaic Virus (WSpMV)

Wheat spot mosaic virus (WSpMV) is vectored by *Aceria tosichella* – an eriophyid mite species, also found vectoring WSMV. Wheat spot mosaic virus is acquired by nymphs as well as adults. In some cases, wheat fields are found simultaneously having both WSMV and WSpMV diseases. Wheat spot mosaic virus disease causes a very distinct mottling and spotting on many corn varieties and on barley, oats, rye and a number of annual grasses. This virus disease is also reportedly vectored by an eriophyid mite, *Aceria tulipae*, which is mainly found on liliaceous plants. At early stages of infection, toxic effects of mite feeding are also attributed as cause, but in WSpMV, symptoms continued to develop even after the plants were freed of mites. The disease is not spread transovarially (Jeppson et al. 1975).

Virus-caused symptoms varied greatly in severity. In some cases extreme chlorosis and death of the emerging plants are reported. Plants infected simultaneously with both WSMV and WSpMV were more severely diseased than plants infected with either virus alone. Some of the mites from plants infected with both WSMV and WSpMV carried both the viruses, but a higher percentage of the mites transmitted WSpMV than WSMV.

16.1.3 Ryegrass Mosaic Virus (RgMV)

Ryegrass mosaic virus (RgMV) is a member of the potyvirus of plant viruses. Ryegrasses are the most important hosts but other grasses such as cocksfoot (*Dactylis glomerata*), fescue and annual meadow grass (*Poa annua*) can be infected. RgMV has a worldwide distribution and is considered to be the most serious and widespread sap-transmissible virus infecting Gramineae in Britain, Australia and New Zealand. RgMV causes light green to yellow flecking and streaking of ryegrass leaves which is followed by necrosis and death of the tiller Italian ryegrass (*Lolium multiflorum*), some perennial grasses, rice and oats, but not on wheat and other hosts of WSMV. Eriophyid mite, *Abacarus hystrix*, transmits RgMV. When reared on diseased ryegrass, all stages of the mite except the eggs carried the virus. Non-infective mites acquired the virus within 2–12 h of feeding on a diseased plant. In the absence of a virus source, viruliferous mites lost infectivity in less than 24 h of leaving infected leaves. All instars of *A. hystrix* transmitted the virus (Malligan 1960).

16.1.4 Agropyron Mosaic Virus (AMV)

Agropyron mosaic virus (AMV) has been found on *Agropyron repens* in some parts of the USA and Canada. Eriophyid mite, *Abacarus hystrix*, has been reported as vector of AMV in some parts of Canada and causes mosaic symptoms similar to wheat streak mosaic virus (WSMV) disease (Slykhuis 1969). The virus is readily sap transmissible and has particles similar to WSMV but is only distantly related to WSMV serologically. AMV spreads from *A. repens* to wheat during the warm summer weather in Ontario region of Canada. Virus transmission by eriophyid mites *Aceria tulipae*, *Abacarus hystrix* and *Vasates mckenzie* on *Agropyron repens* has not been demonstrated.

16.1.5 Fig Mosaic Virus (FMV)

Eriophyid mite, *Aceria ficus*, has been reported as a vector of fig mosaic. Disease symptoms include mottling, spotting and distortion of youngest leaves and later vein clearing and a systematic mosaic of varying intensities. Sometimes disease-infected leaves and fruits may even drop (ER4). Ten or more days are required for appearance of disease. The fig mosaic virus is graft transmissible but not sap transmissible. FMV disease causes a serious problem for the fig growers in Egypt and many other places. Biological and molecular characterization of FMV has been reported recently from Egypt (Haffez et al. 2011).

Eriophyid mite, *Aceria ficus*, lives in buds during the dormant season. In spring, mites spread to developing leaves, laying eggs among the thick mat of trichomes on the lower leaf surface. Mites infest fruits, leaves, buds and young green twigs. Fig mosaic virus has been reported from India, Germany and the USA. Transmission occurred after access to an infected plant for only 5 min. Both nymphal and adult mites are able to acquire the pathogen and transmission can occur within a few hours after acquisition. Mites retain the ability to transmit after moulting and adults remain inoculative 6–10 days after removal from infected plants, but the pathogen is not transmitted transovarially. For management of FMV disease, never plant fig cultivars that are propagated from mosaic infected trees. By controlling fig mites, disease incidence can also be reduced.

16.1.6 Peach Mosaic

Virus disease is transmitted by an eriophyid mite vector, *Eriophyes insidiosus*. Peach mosaic-affected trees have leaves which are often small, narrow, crinkled and irregular in shape; leaves of affected trees have mosaic pattern. Internodes of affected trees become shortened and a profuse growth of leaf axil buds is found. Colour breaking of blossoms and rosetting of branches of peach and certain other *Prunus* (plums, apricots and almond) host plants. and peach mosaic virus disease have been reported from south-western USA and Mexico. Mites are found more commonly beneath bud scales. Regular nursery inspection, removal of infested trees and adopting different quarantine measures help in limiting the spread of the mite vector of disease.

16.1.7 Cherry Mottle Leaf Virus (CMLV)

Cherry mottle leaf virus (CMLV) disease is transmitted by an eriophyid mite vector, *Eriophyes inaequalis*. Disease symptoms include irregular chlorotic mottling, edge tattering and reduction in size of leaves. CMLV has been reported from cherry growing areas of the USA, Canada, European countries (where cherry grows) and South Africa. Fruits on infested trees appear normal but they lack flavour and often ripen late (ER7). *Prunus emarginata* is the only known wild host. Cherries grown in the foothill locations where bitter cherry occurs are at greater risk of infection. With infected wood CMLV is spread by budding and grafting and by the vector mite, *E. inaequalis*. Trees on the orchard's edge usually are infected first. Removal of infected trees prevents new infections and also destroys stands of wild cherry near commercial orchards. Virus-free nursery stock and scion should only be used.

16.1.8 Currant Reversion Disease

Blackcurrant reversion is a viral disease commonly found on blackcurrants (*Ribes nigrum*) worldwide; it also affects redcurrants (*R. rubrum*) but not gooseberry (*R. uva-crispa*). The disease is particularly widespread in blackcurrants in Eastern and Central Europe, Russia, in some parts of the UK and Scandinavia and New Zealand. In nature, the causal agent of the disease is transmitted between plants by the blackcurrant gall mite, *Cecidophyopsis ribis*, but not through the seed. However, the disease can be transmitted between infectible *Ribes* plants by grafting. Two forms (strains) of reversion are distinguished: the common European form (E) and the more severe R form found in Finland and some other countries of erstwhile Soviet Union. The two forms differ in the severity of symptoms expressed in blackcurrant plants but the progression of the disease both in plants and crops is similar with each of this form. Compared to leaves of healthy plants, the leaves of diseased reverted plants are narrower, show a decreased number of the main veins and have larger but fewer marginal serrations. Flower buds of infected plants develop strong malformations including the absence of stamens, elongation of the style and increase in number of petals. Affected flower buds are usually sterile causing a severe loss in fruit productivity. The leaf markings often disappear as the leaves age and are usually not evident on growth made during the summer (Jeppson et al. 1975; Slykhuis 1969).

For prevention and control of blackcurrant reversion disease, immersion in hot water (46 °C for 10–20 min) is reported to eradicate the vector (gall mites). Planting of healthy (certified) plant material away from sources of infection also proves helpful in controlling reversion disease. Successful chemical control of eriophyid mites requires the accurate timing of applications to coincide with mite dispersal. But blackcurrant reversion disease is the most destructive disease of blackcurrants, and once established in the crop with its vector, it is very difficult to control.

16.1.9 Pigeon Pea Sterility Mosaic Disease (PPSMV)

PPSMV is characterized by a bushy and pale green appearance of plants, excessive vegetative growth, stunting, reduction in leaf size, leaf distortion and mosaic of leaves. Complete or partial cessation of flowering (sterile) occurs. The disease has been reported vectored by an eriophyid mite, *Aceria cajani*, from India, Bangladesh, Sri Lanka, Nepal and Myanmar (ER3). The mite is highly host specific, confined mainly to pigeon pea and its wild relatives. Mites have a life cycle of about 2 weeks, are found on the lower surface of leaflets and are found predominantly on symptomatic leaves of PPSMV-infected plants. Some studies suggested a semi-persistent mode of transmission of PPSMV by *A. cajani.* PPSMV causing sterility mosaic disease (SMD) is considered as ‘green plaque of pigeon pea’. Vector mite, *A. cajani*, is one of the major biotic factors, leading to heavy yield losses, and hence poses a big challenge for pigeon pea production in the Indian subcontinent. Wettable sulphur is reported to be very effective in controlling vector mites (Kulkarni et al. 2002; Latha and Doraiswamy 2008; Manjunatha et al. 2012).

The disease may be controlled possibly by removing all old plants in the vicinity in annual crops and by removing all old pigeon pea plants growing as perennials in the vicinity well before sowing the new crops.

16.1.10 Rose Rosette Disease (RRD)

RRV is a devastating disease and is a threat to virtually all cultivated roses (*Rosa* spp.). Losses can occur in home and commercial landscapes. The causal agent of RRD disease remains unknown. At present, researchers refer to the causal agent as a virus or virus-like agent. RRD is vectored or transmitted by an eriophyid mite, *Phyllocoptes fructiphilus*. Mites feeding on diseased hosts are able to acquire the disease agent and transfer it to the new plants; RRD can be transferred to healthy plants by grafting. The symptoms of RRD may include red colourations or mosaic on leaves and shoots; leaf size reduction, distortion and severe roughening; and even increased thorniness and reduction in flowering. Eventually death of the entire plant affected by RRD occurs (ER8).

Mite vector is host specific (like most other eriophyid mites) on members of the genus *Rosa*. Commonly the disease symptoms are known as ‘rosette of rose’ in the USA, and such symptoms are reported from many rose species, cultivars and varieties of wild and cultivated roses. Multiflora roses (*Rosa multiflora*) originally used as fence is highly susceptible to RRD. Cultivated roses growing near infected multiflora roses have a high risk of infection. There is no cure for RRD once bushes become infected. So, early detection is essential to prevent the disease to nearby roses. Always purchase new roses from a reliable nursery after inspecting for RRD; remove multiflora roses from within 100 metres of cultivated roses whenever possible. Adopt proper spacing of cultivated roses so that plants do not touch each other and dispersal of disease vector may occur. Remove infected plants including roots completely; remove and destroy any regrowth that occurs.

16.2 Plant Viral Diseases Vectored by False Spider Mites

In the mite family Tenuipalpidae, one or more species within the genus *Brevipalpus*, *Cenopalpus*, *Dolichotetranychus*, *Raoiella* and *Tenuipalpus* are sometimes recognized as serious economic pests. However, only three species within genus *Brevipalpus* are known to vector one or more cytoplasmic- or nuclear-type plant viruses (Childers and Derrick 2003; Childers and Rodrigues 2011). A brief account of virus–vector relations, biology of mite, disease symptoms and their management is discussed below.

16.2.1 Citrus Leprosis

'Citrus leprosis' is caused by two viruses, namely, cytoplasmic type (CiLV-C) and nuclear type (CiLV-N). Tenuipalpid mite, *Brevipalpus phoenicis*, has been reported as the vector of citrus leprosis virus disease. *Brevipalpus californicus* and *B. obovatus* have been reported in some literature associated with citrus leprosis symptoms, but only *B. phoenicis* has been proven to be an effective predator. The virus in *B. phoenicis* is transmitted transtadially but not transovarially. Citrus leprosis has been mechanically transmitted from citrus to citrus (Knorr 1968). The disease produces chlorotic lesions on the fruit and leaves that do not result in systemic infections (Bastianel et al. 2010). Differences in chlorotic patterns occur in different varieties. Premature fruit drop, defoliations and death of the twigs can occur with devastating results. Death of a twig or branch results when they become girdled by individual lesions (ER5). The disease only spreads when both infected trees and mite vector are present. If the mite vector is not controlled, CiLV-C can kill a tree within 3 years. Citrus species especially sweet oranges (*Citrus sinensis*) and some mandarin (C. eticulata) varieties are comparatively more infected by the mites which seriously threatens orange production in prone areas. Citrus leprosis has been reported as an important disease in Brazil, Argentina, Paraguay, Bolivia and Colombia (in South America); Panama, Guatemala, Costa Rica and some other parts of Central America; and North America (Florida, USA) (Childers et al. 2003a, b, c; Jeppson et al. 1975; Knorr et al 1968).

16.2.2 Passion Fruit Green Spot Virus (PGSV)

Passion fruit green spot virus (PGSV) is a cytoplasmic virus disease. Tenuipalpid mite, *Brevipalpus phoenicis*, is the only known vector of PGSV. In case of severe outbreaks of disease, considerable leaf and fruit drop occurred and high populations of vector mite are reported on passion fruit (*Passiflora edulis*). This disease has been reported from Brazil. PGSV disease-affected mature yellow fruits showed characteristic green spotting; patches of green spotting on the leaves are also found. Most serious damage resulted from necrotic lesion that girdles the stems and kills the plants. These spots may be uniformly green with a central necrotic depression. The virus does not move systemically in the plant which resulted in subsequent death of the plant and eventually in the destruction of the entire orchard (Kitajima et al. 2003).

16.2.3 Coffee Ring Spot Virus (CoRSV)

From Brazil and Costa Rica, tenuipalpid mite *B. phoenicis* has been reported as a vector of coffee ring spot virus. Conspicuous localized ring spot lesions on both leaves and berries are found. A reduced number of coffee berries are found resulting in lowered yields. The disease caused premature fruit and leaf drop in affected plants. CoRSV remains restricted to lesion areas. The spread of CoRSV can affect the coffee industry throughout Central Africa (Chagas et al. 2003).

16.2.4 Orchid Fleck Virus (OFV)

Tenuipalpid mite, *Brevipalpus californicus*, is reported as vector of orchid fleck virus from Australia, Brazil, Germany, Japan, Korea and the USA. Orchid fleck virus (OFV) is a nuclear type of virus and its actual distribution is likely to be much higher. OFV produces chlorotic or necrotic spots and rings on the leaf fronds of many genera of Orchidaceae (Kondo et al. 2003).

16.3 Plant Viral Diseases Vectored by Spider Mites (Tetranychidae)

Barley yellow streak mosaic virus (BaYSMV) from Alberta (Canada) and Alaska (USA) has been reported from dry land barley (*Hordeum vulgare*). Based on virus particle shape and size, symptomatology, mechanical transmission, host range and serology, BaYSMV is associated with the barley disease. BaYSMV disease outbreaks are associated with recurring drought and are accompanied by infestations of the brown wheat mite vector, *Petrobia latens*, which is found under drought conditions. Brown wheat mite has been observed as a vector of BaYSMV. The disease also reported transferred to *Nicotiana benthamiana* and *Chenopodium quinoa* by the mechanical transmission with sap from diseased barley leaves. Early symptoms of streak mosaic virus disease resemble the feeding damage of non-viruliferous mites. Diseased barley and wheat leaves appear light green to pale yellow. As the disease progresses, the leaves acquire light green to yellow dashes and streaks. In addition some leaves display a uniquely diagnostic symptom pattern of yellow banding wherein a wide band parallel to the mid-vein on one half of the leaf is discoloured, whereas the other half is a symptomatic dark green. Most infected plants exhibit moderate to severe diversing. Brown streaks appear on the leaves; in some cases the extremely diseased plants die (Robertson and Brumfield 2000; Smidansky 1996).

16.4 Plant Fungal Diseases Vectored by Eriophyid Mites

16.4.1 Mango Malformation Disease (MMD)

Since long bud mite, *Aceria mangiferae,* has been reported to be associated with the mango malformation disease, there has been controversy regarding the role played by this mite and the fungal pathogen, *Fusarium moniliforme* var. *subglutinans*. In recent studies, *F. subglutinans* has been recognized as the causal agent of mango malformation, associated with floral and vegetative malformation of mango, and *A. mangiferae* may play a role as carrier of fungal pathogen.

MMD has been reported from Australia, Africa (Egypt, South Africa, Sudan and Uganda), India, the USA and some other parts of the world where mango is grown. MMD spreads on a tree very slowly but if left unchecked can reduce mango yields. Mango bud mite, *A. mangiferae*, has been shown to spread the disease within a tree and not between trees. *A. mangiferae* is found mostly on apical growing buds rather than on the lateral dormant buds. Within the buds, *A. mangiferae* are found in peripheral scales than in the meristematic dome within the apical bud. The upper and middle canopy of the tree reported are more preferred than the lower canopy by mites. The mite is reported commonly on buds and inflorescences of the mango. The main spread of MMD to new areas is by infected pruning equipment or vegetative planting material (ER6).

16.5 Management of Mite-Vectored Plant Viral Diseases

Once plants are infected, little can be done to free them from the virus. Although the use of resistant varieties has been found to be the best economical and practical approach for effective management of viral diseases, an integrated approach is essential in sustainable agriculture. Development of integrated management requires correct identification of the causative viruses, because symptoms can be misleading, and adequate understanding of the ecology of viruses and their vectors. The following approaches need to be considered for developing such an integrated management:

- *Genetic host resistance*. Resistant type of plants should be planted whenever they are available. Recent advances in plant cell molecular biology and virology have lead to the development of genetically modified plants with superior resistance to some viruses.
- *Cultural practices*. Scouting and removal of symptomatic plants or known alternative weed or volunteer plants that may serve as a reservoir for a given virus. Encourage rotation to non-host crops; always use clean or sanitized tools and equipment at the farms. Some viruses are permanently relatively inactivated by prolonged exposure of the infected tissue to high temperatures (at 38 °C) for 20–30 days. Heat therapy frees individual plants or cuttings of the virus and thus the clean tissue is used as a propagative source, allowing large-scale production of virus-free plants.

- *Chemical applications*. As such there are no chemical sprays or biological control approaches to eradicate viruses, although such approaches can be used to control mite vectors.
- *Regulatory measures*. Management of mite vector populations in the field can be difficult or impossible unless coordinated on a regional basis, but may be highly effective in closed production systems such as greenhouses.

16.6 Conclusions

Mite-borne plant viruses may cause severe losses to many annual and perennial crops in the tropics and semi-tropics where ideal conditions for perpetuation of both viruses and their vectors are available. Many worm mites (Eriophyidae), false spider mites (Tenuipalpidae) and spider mites (Tetranychidae) which possess piercing and sucking mouthparts are known as vectors of virus diseases of cereals, fruit trees, pigeon pea and coffee plants. Viral diseases like 'wheat streak mosaic virus' (WSMV), 'wheat spot mosaic virus' (WSpMV), 'ryegrass mosaic virus' (RgMV), 'fig mosaic virus' (FMV), 'currant reversion disease' (CRV), 'pigeon pea sterility mosaic disease' (PPSMV) and 'rose rosette disease'(RRD) are all vectored by eriophyid mites and cause significant losses under ideal conditions. But virus diseases like 'citrus leprosis', 'coffee ring spot virus' and 'passion fruit green spot virus' are vectored by false spider mite (*Brevipalpus phoenicis*). Another virus disease known as 'barley yellow streak mosaic virus' (BaYSMV) is reported vectored by spider mite (*Petrobia latens*). In addition to virus diseases, a fungal disease, namely, 'mango malformation disease' (MMD), is also associated with eriophyid mite (*Aceria mangiferae*). Information on damage symptoms and measures to manage these diseases under field conditions is given under each disease.

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