Chapter 14

Whitefly-Transmitted Viruses

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General Introduction

Whiteflies belong to the order Homoptera, family Aleyrodidae, and are currently reported to transmit 28 different plant viruses of beans and other crops (71, 120). Whitefly species reported to be vectors of plant viruses include *Bemisia tabaci* Gennadius *(=B. inconspicua* Quaintance), *B. lonicerae, B. manihotis* Frappa, *B. tuberculata* Bandar, *B. vayassieri* Frappa, *Aleurotrachelus socialis* Bondar, *Aleurothrixus floccosus* Mask, *Trialeurodes abutilonea* Haldeman, *T. natalensis* Corb. and *T. vaporariorum* Westwood (13, 32, 36, 91, 106). Whitefly populations are commonly restricted to tropical zones below 1300m, where they are capable of transmitting viruses to various plant species (13, 32, 36, 61, 68, 95, 102, 119, 120).

Bemisia tabaci is the most common whitefly vector of bean viruses and is variable in its feeding habits and reproduction rates on different plant species. Flores and Silberschmidt (56) and Russell (107) characterize this variation as biotypes. However, Bird (9, 10, 11, 14) denotes the variation as races, *B. tabaci* race *jatrophae* and *B. tabaci* race *sidae.*

The virus diseases transmitted by whiteflies *(B. tabaci)* are grouped into two main types by Costa (52) according to their symptomatology. These types are mosaic and leaf curl.

A green, or more frequently yellow, mosaic of foliage is the most conspicuous symptom in the mosaic group. Yellowing may appear along the veins and develop into a yellow net or be limited by the veins. Curling or crinkling of the foliage may occur due to the abnormal or unequal growth of healthy and infected mosaic areas of the leaf. As the foliage matures, the mosaic tends to become less apparent, and for certain diseases, such as cotton common mosaic, the yellow areas may turn reddish late in the season (28). In the case of *Malva parviflora* infected with the disease agent from *Abutilon thompsonii,* the initial mosaic is followed by witches' broom symptoms (58). The characteristic yellow or golden color of infected plants is easy to distinguish from healthy plants in a field.

In the case of leaf curl, infected plants do not exhibit clear mosaic symptoms but may show a diffused yellowing of leaves and vein clearing which may be easily overlooked. The characteristic symptom caused by this group is the stunting of infected plants, curling, enation, and vein thickening of foliage.

Costa (36) recently included a third group of whitefly-transmitted viruses which produces yellowing symptoms to distinguish from similar symptoms induced by aphid-transmitted viruses or nutritional disorders. Yellowing symptoms induced by whitefly-transmitted viruses commonly appear only later during plant development.

Symptomatological differences suggest that the first group of viruses occurs in parenchymatous tissue and the second group occurs in phloem vessels (32). However, some diseases may induce symptoms of the first group in some hosts and symptoms of the second group in other hosts. For example, the disease agent from infected *Rhynchosia minima* induces a bright yellow mosaic symptom on *Rhyncosia minima* but induces leaf curl and enation on tobacco (11). Duffus (54) also mentions two major groups of whitefly-transmitted viruses identified as variegation-producing and plant malformation-producing types.

Very few whitefly-transmitted diseases have been isolated and proven to have a viral etiology. The previously mentioned groups of viral diseases have been based upon arbitrary classifications due to similarities in symptomatology and presumed insect vectors. Bird *et al.* (20) suggested that these whitefly-transmitted viruses with unknown or incomplete etiology be placed in one group, rugaceous diseases, instead of different groups primarily distinguished only by symptomatology. Much organized and collaborative research is required to characterize these whitefly-transmitted viruses and establish their true relationships.

The following viruses of beans and other plant species have been demonstrated to be whitefly-transmitted, many however, only under research conditions. These viruses are grouped in order of their decreasing economic importance: a) bean golden mosaic; b) bean chlorotic mottle, abutilon mosaic, yellow dwarf mosaic, infectious chlorosis of Malvaceae; c) euphorbia mosaic; d) rhynchosia mosaic; e) jatropha mosaic; f) jacquemontia mosaic; g) ipomoea or merremia mosaic; and h) mung bean yellow mosaic.

The following sections of this chapter will review the geographical distribution, economic importance, host range, symptomatology, physical properties, transmission, epidemiology and control measures reported for these viruses.

Bean Golden Mosaic Virus

Introduction

Bean golden mosaic virus (BGMV) was first reported in Latin America in 1961 (31), at which time it was considered to be a minor disease in Sao Paulo, Brazil. It has since occurred in practically every major bean production area in Brazil, including Minas Gerais, Parana, Bahia, Pernambuco, Ceara, Para, the Amazon, and the Valle del Río Sao Francisco (33, 44, 121). BGMV has been reported in many other bean production regions of Latin America, such as El Salvador (66, 67, 126, 127), Guatemala, Nicaragua, Costa Rica, Panama (66, 67), Puerto Rico (12, 17, 21), Jamaica, Dominican Republic (1, 2, 101, 102, 108), Colombia (63), Cuba (23), Belize, Mexico, Honduras and Venezuela (Gálvez, personal observations).

Identification and nomenclature of BGMV has been quite diverse and must be standardized between workers in different regions, since BGMV-like symptoms have been called BGMV, bean yellow mottle, bean golden yellow mosaic, bean yellow mosaic and bean double yellow mosaic (12, 17, 21, 46, 47, 48, 108, 126, 127). Gálvez *et al.* (64) utilized serology, electron microscopy and density gradient centrifugation to prove that isolates inducing similar disease symptoms in Mexico, Guatemala, El Salvador, Colombia, Cuba, Puerto Rico, Dominican Republic, Brazil and Nigeria all were bean golden mosaic virus. This relationship between isolates also should be clarified by utilization of the BGMV antisera developed by Goodman (75) from isolates collected in Puerto Rico.

Bean golden mosaic virus is an economically important disease, especially in regions of Latin America such as Brazil and parts of Central America and the Caribbean. Brazilian bean production has been reduced greatly by the virus since 1972, and its seriousness has been attributed to the increasing whitefly populations associated with the expanded production of soybeans in bean growing areas (33, 44, 121). Gámez (66, 67, 70) considers BGMV to be the principal bean disease in the Pacific coastal plains of El Salvador, where disease incidence frequently reaches 100%.

Various workers (42, 69, 101, 102) report that infection by BGMV reduces the number of pods, number of seeds per pod and seed weight. Reported yield losses consist of 57% in Jamaica (101, 102), 48-85% in Brazil (42, 90), 40-100% in Guatemala (96), and 52-100% in El Salvador (Cortez and Diaz, personal correspondence). Yield losses vary greatly depending upon plant age at the time of infection, varietal differences and possibly viral strains (33, 61).

The host range of BGMV includes *Phaseolus vulgaris, P. lunatus, P. acutifolius, P. polystachios, P. longepedunculatus, P. aborigeneus, P. coccineus, Desmodium occuleatum, Macroptilus lathyroides, Terramnus urcinatus, Vigna radiata, V. unguiculata* and *Calopogonium muconoides* (2, 4, 12, 13, 20, 21, 27, 31, 33, 34, 35, 36, 51, 57, 68, 79, 102, 122, 124).

Common names frequently used for bean golden mosaic virus in Latin America include mosaico dorado del fríjol, moteado amarillo del fríjol and mosaico dourado do feijoeiro.

Symptomatology

Symptoms of BGMV are readily visible in infected bean plants which exhibit a brilliant yellow or golden color of leaves (Fig. 1). Symptoms may appear in the primary leaves within 14 days after planting if high populations of whiteflies are present in or near the field. Bird *et al.* (20, 21) observed the presence of small yellow spots, sometimes apparent as star-shaped lesions, near the leaf veins three to four days after exposure to viruliferous whiteflies.

The primary systemic symptoms of BGMV infection are apparent as rolling of the lower leaf surface of young leaves, which later exhibit a range of mosaic symptoms (Fig. 2). These symptoms are predominant near the veins and within the leaf parenchymatous tissue, where an intense and often brilliant yellowing develops. Susceptible cultivars exhibit a marked rugosity and rolling of leaves, many of which may be completely yellowed or occasionally white to nearly bleached. Tolerant cultivars often present symptoms with less intense leaf mosaics and may exhibit some plant recuperation at a later stage of development.

Most cultivars do not show a reduction of leaf size (33). When the infection occurs during the seedling stage, susceptible plants may become stunted. Pods of infected plants may exhibit mosaic spots or be malformed (Fig. 3). Seeds may be discolored, malformed, and reduced in size and weight (24, 66, 67).

The symptomatology of BGMV appears to be similar to that reported for lima bean golden mosaic virus in Africa (122) and lima bean yellow mosaic in India; but the latter differs in its host range (95, 105). Mung bean yellow mosaic, urd bean yellow mosaic viruses and yellow mosaic of *Dolichos lablab* likewise are not able to infect the majority of *Phaseolus vulgaris* cultivars (104). However, these viruses appear to have a similar symptomatology on their respective hosts as does BGMV in beans (92, 93, 95, 104, 128).

Fig. 1- Symptoms induced by bean golden mosaic virus in beans.

Electron microscopy evaluations of infected bean tissue reveal that the principal cellular symptom is evident as a dramatic change in chloroplast morphology, particularly in the lamellar system (81). Recently Kim *et al.* (80) reported that the symptoms are limited to the phloem tissue and cells adjacent to the parenchyma tissue. Virus-like particles appear as packed hexagonal crystal arrangements or as loose aggregates in the nuclei of infected cells. Distinct changes in the nucleoli also are evident, since there is a segregation of granular complexes and fibrils which may occupy 75% of the nuclear volume (76).

Physical Properties

Bean golden mosaic virus has been classified as a viral disease because of its characteristic transmission by insects, symptomatology and mode of dissemination in the field (21, 31, 68, 85, 101). However, its viral etiology was not completed until its isolation was accomplished in 1975 by Gálvez and Castaño (62). They observed that fixed BGMV has a specific form which consists of icosahedral particles united in pairs (identical dimer particles or geminates). The bonded particles are flattened at their point of

Fig. 2- Mosaic symptoms and leaf malformation induced by BGMV infection.

Fig. 3- Pod malformation caused by BGMV infection of a susceptible bean cultivar.

union (Fig. 4) and measure 19 x 32 nm, while individual particles have a diameter of 15-20 nm. Matyis *et al.* (87) reported individual particles measured 12-13 nm in diameter. A similar particle morphology was found for the viruses causing tomato golden mosaic, euphorbia mosaic (86, 87) as well as BGMV of beans in Brazil, Colombia, El Salvador, Dominican Republic, Guatemala, Mexico, and BGMV of *P. lunatus* from Nigeria (64).

Goodman *et al.* (77) could not determine whether these geminate particles actually were the infectious entities or artifacts of fixation. However, Gálvez and co-workers (24, 62) could observe particles in unfixed preparations, and they gave the highest infectivity. When the BGMV particles were disassociated with EDTA at high molarity (0. 1M), infectivity was almost completely lost.

BGMV particles have a thermal inactivation point of 50°C (18, 19) to 55°C (62), a final dilution end-point of 10^{-1} (62) to 10^{-2} (*18, 19*), and an *in vitro* longevity of 48 hours at room temperature (62). Goodman and co-workers (76, 77) determined that the particles have a sedimentation coefficient value of 69 S, a molecular weight of 2.6×10^6 daltons, a 260 nm absorbance value of 7.7 and a 260/280 absorbance ratio of 1.4. The genome of BGMV contains DNA which has a sedimentation coefficient of 16 S, a molecular weight of 0.75×10^6 daltons, and composes 29% of the particle (24, 25, 72, 73, 76). Two protein components, of molecular weight 3.8×10^4 and 5.5×10^4 daltons, were isolated by Cárdenas and Gálvez (24, 25). The DNA is single stranded and resistant to exonucleases (24, 74). It has a buoyant density of 1.717 g/ml in cesium chloride and is resolved into two components during polyacrylamide gel electrophoresis in 8 M urea (74, 77).

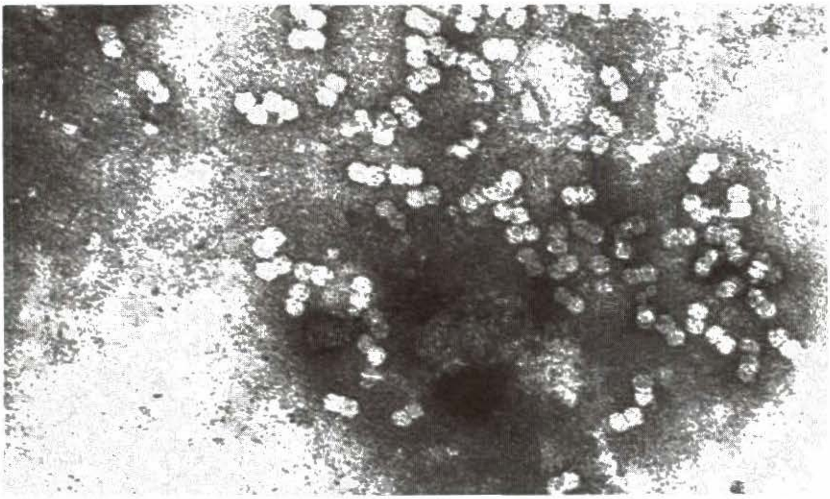

Fig. 4- Geminate particles of bean golden mosaic virus (160,000 X).

Francki and Bock (60) have included BGMV in a new virus group called the Geminivirus, based upon its particle characterization, physical-chemical properties and single-stranded DNA.

Transmission and Epidemiology

BGMV can be transmitted naturally by whiteflies and artificially by mechanical inoculation. Other whitefly-transmitted plant viruses such as euphorbia mosaic, abutilon mosaic and sweet potato virus B also have been transmitted mechanically (32, 36). However, Meiners *et al.* (88) were the first workers to mechanically transmit BGMV to beans. Successful inoculation required a high temperature of 30°C, and a 30% transmission rate was obtained at 24° - 28°C. No transmission occurred below 21°C. Bird and co-workers (16, 19) originally obtained only a 4% transmission but have since improved this efficiency.

Gálvez and Castaño (62) obtained nearly 100% transmission under glasshouse conditions at 25°C with BGMV inoculum extracted from plants infected 21 days earlier in a 0.1 M phosphate buffer at pH 7.5 and 1% 2-mercaptoethanol. Transmission was significantly reduced or zero if inoculum was extracted from plants infected after 21 days. Bird *et al.* (19) utilized a similar buffer at pH 7.0 to obtain 100% transmission by inoculation with an airbrush at 80 lb/in^2. Matyis *et al.* (87) were not able to transmit BGMV isolates mechanically in Brazil, which may reflect differences in methodology or strains. Some strains of BGMV may be transmissible only by the whitefly vector (36, 41, 76).

BGMV has not been shown to be transmissible in seed from infected bean plants. Pierre (102) tested seed from 300 infected bean plants, and Costa (31, 33, 34, 36) tested seed from 350 infected lima bean plants. None of these seeds was found to be infected by BGMV.

The principal mode of BGMV transmission, especially under field conditions, occurs from the whitefly vector, *Bemisia tabaci*. Whiteflies are able to extract plant sap, but the principal threat to crop productivity is their ability to transmit plant viruses. Costa (32) stated that the whitefly is able to transmit viruses to more than 16 plant species, including cultivated and non-cultivated plants.

Nene (94) has studied the biology of whiteflies in relation to legumes such as *Phaseolus aureus, Vigna mungo* and *Glycine max*. The insect can produce 15 generations a year, during which time populations may be restricted to a single crop species or migrate to a variety of plant species. A whitefly may lay 38-106 eggs (Fig. 5) during its life cycle, which requires 13-20 days during March to October or 24-72 days during November to March in India. Populations of whiteflies are reduced as the mung bean crop matures. These populations then may migrate to other plants such as crucifers, lentils and peas.

The life cycle on cotton in India (107) varies from 14-107 days, is shortest during April to September (14-21 days), and is longer during November to February (69-72 days). The maximum oviposition occurred at temperatures greater than 26.5°C, and no oviposition occurred at temperatures below 24°C.

Adults of *B. tabaci* are able to transmit BGMV in a circulative manner. There is no evidence of transovarial transmission or virus multiplication within the whitefly (32, 36, 95).

Costa (32) states that whitefly-transmitted viruses are not acquired as rapidly as aphid-transmitted viruses. Inoculation efficiency increases more because of longer acquisition periods than because of differences in virus infectivity. Whitefly-transmitted viruses have a defined but shorter incubation period, and particles are retained for more than 20 days in the insect vector. Whitefly adults can acquire and transmit BGMV within 5 minutes (7, 21, 68), and the inoculation efficiency is increased as population size is increased per infected plant (7, 13, 32, 36, 68, 120). Gámez (68) found an average acquisition and incubation period of three hours each. The retention period varies according to the acquisition period but may reach 21 days or the entire life of the whitefly (7, 20, 32, 36, 68, 120). The insects occasionally have been observed to lose their capacity for transmission (68).

Immature forms (Fig. 6) are able to acquire mung bean yellow mosaic virus which persists during pupation and can be transmitted during the

Fig. 5- Eggs and immature forms of *Bemisia tabaci* on the lower leaf surface.

Fig. 6- Immature forms of *Bemisia tabaci*.

Fig. 7- The adult whitefly (*Bemisia tabaci*) vector of BGMV.

adult stage. At least 50% transmission has occurred from adults (Fig. 7) obtained from immature forms which had previously fed on infected plants (95, 105). Costa (35) reported that female whiteflies were more efficient than males as vectors of BGMV to *Phaseolus vulgaris, P. acutifolius* and *P. polystachios*. However, males were more efficient vectors on *P. lunatus* and *P. longepedunculatus*.

BGMV is not seed-transmitted and, therefore, probably exists in many regions in plant reservoirs such as lima beans and other susceptible legumes including voluntary and cultivated beans, and weeds (34, 36, 51, 52, 61, 68, 102). Pierre (102) considers that lima beans and *Macroptilium lathyroides* are natural hosts for BGMV in Jamaica, in addition to poinsettias *(Euphorbia pulcherrima)*. Increased production of soybeans has increased whitefly populations and BGMV incidence greatly in beans planted in Parana and Sao Paulo, Brazil (33, 44, 121). Tobacco, tomato and cotton plantings in El Salvador and Guatemala are responsible for the high whitefly populations in those countries (5, 6, 27, 52, 61, 78).

Bean golden mosaic virus is more prevalent in lower to intermediate elevations (13, 33), normally below 2000 m where whitefly populations, temperatures and inoculum sources are greater. BGMV incidence is less during November to March when temperatures and insect vector populations are lower in Jamaica, Cuba and the Dominican Republic. BGMV is more common and severe in Brazil at elevations between 400-800 m and near the end of the summer or dry period (January to February) when whiteflies migrate from other maturing crops, such as soybeans, to the young bean plantings. Whitefly populations decline rapidly during cooler periods of the year, when temperatures are unfavorable to the whitefly and when fewer susceptible crops exist (31, 33).

Control by Cultural Practices

The incidence of BGMV in a bean production region can be reduced by eliminating alternative plant reservoirs of inoculum such as volunteer plants of *Phaseolus vulgaris, P. lunatus, P. longepedunculatus, Calopogonium* sp. and other plant species. Crop rotation and distribution within a production region also are important. BGMV incidence is increased greatly by planting beans near fields of soybeans which, although not susceptible to BGMV, are favorable for whitefly populations which may encounter and transmit BGMV from infected plants, such as *Sida* spp. and other hosts, to developing bean crops (33, 102). BGMV infection of beans can therefore be reduced by not planting beans near fields of other crops such as soybeans, tomatoes, tobacco and cotton, which favor the build-up of whitefly populations.

Date of planting should be varied, if possible, so that young bean plants develop during periods of lower temperature and higher moisture which are less favorable to the whitefly and its ability to transmit BGMV (5, 6, 23, 31, 32, 33, 36, 44, 70, 78, 102).

No economical and practical biological control measures are currently available (95, 109). Plant mulches have been shown to reduce whitefly populations (8), possibly due to altered air temperature near the plants.

Control by Chemicals

The whitefly vector can be controlled by applying insecticides to economically reduce the population size and incidence of BGMV tranmission to susceptible cultivars. Various insecticides are effective against whiteflies *(Bemisia tabaci* and *Trialeurodes vaporariorum).* These include Tamaron 600E (1 lt/ha), Nuvacron 60 (0.5 lt/ha), Folimat 1000 (0.5 lt/ha), Bux 360 and Thiodan 35 or Endosulfan (1.5 lt/ha) (50). Populations of whiteflies were reduced effectively in El Salvador by applying Tamaron 600 (1 lt/ha) every seven days during the first 30 days after plant emergence (53, 82, 83). Alonso (6) reported that Nutasystox R-25 (1 lt/ha), followed by Nuvacron 50 (1.5 lt/ha) and Folimat 80 (0.33 lt/ha), effectively controlled whiteflies when applied 15 and 30 days after planting.

Systemic insecticides, such as Furadan and Thimet, effectively control whitefly populations when applied at planting (6). Substantial yield increases were obtained in the Dominican Republic by applying Carbofuran (Furadan 5G) (2.5 g/m row) at planting followed by 0.15% Monocrotophos (Azodrin 60E) applied at six, 15 and 30 days after plant emergence (3, 89, 99, 100). Nene (94) obtained effective control of whiteflies in India with a mixture of (a) 0.1% Thiodan, 0.1% Metasystox and 2% mineral oil, and a mixture of (b) 0.1% Malathion, 0.1% Metasystox and 2% mineral oil. He observed that the mineral oil acted as an ovacide.

Chemical control of insect vectors can be effective and economical in areas with moderate to low disease pressure and whitefly populations. However, its effectiveness can be reduced in regions where high numbers of viruliferous vectors migrate continuously from other infected plant species. Therefore, chemical control may have to be combined with other control measures, such as plant resistance, to achieve a higher level of protection.

Control by Plant Resistance

Plant resistance can provide an economical method of disease control. Workers have evaluated more than 10,000 accessions of *Phaseolus vulgaris*, and some accessions of *P. lunatus, P. acutifolius*, and *P. coccineus* under field and laboratory conditions, but they have not found any source of high resistance or immunity to BGMV (24, 26, 27, 31, 33, 43, 61, 66, 67, 68, 102, 124). However, some accessions have exhibited a low to moderate level of resistance or tolerance, including Porrillo 1 and 70, Turrialba 1, ICA-Pijao, ICA-Tuí, Venezuela 36 and 40, Puebla 441, Guatemala 388 and 417, and CIAT G-651, -716, -729, -738, -843, -951, -1018, -1069, -1080, -1157, and -1257. Various *P. coccineus* accessions from the ICTA germplasm bank are resistant in Guatemala. They include Guat. -1278, -1279, -1288, -1291, -1296, -1299, M7689A and M7719 (24, 26, 27, 79, 124, 125).

Pompeu and Kranz (103) observed field tolerance in Aete-1/37, Aete-1/38, Aete-1/40 (Bico de Ouro types), Rosinha GZ/69, Carioca 99 and Preto 143/106. Rio Tabagi and Goianio Precoce are tolerant in Capinopolis, Brazil (Rava, personal communication). Tulmann-Neto *et al.* (116, 117, 118) obtained a tolerant mutant, TDM-1, by treating seed of Carioca with 0.48% ethyl methanol sulfonate for six hours at 20°C. TDM-1 has a level of tolerance similar to that of Turrialba 1, but it is not as agronomically acceptable.

The tolerance of Turrialba 1, Porrillo 1, ICA-Tuí and ICA-Pijao has been confirmed in Guatemala, El Salvador, the Dominican Republic, Brazil and Nigeria under high disease pressure in bean nurseries inter-planted between tomatoes, tobacco, cotton, and soybeans to favor high whitefly populations (Fig. 8). Glasshouse inoculations and subsequent

Fig. 8- Bean golden mosaic virus screening nursery in the Dominican Republic.

laboratory analyses revealed that these tolerant materials contained lower virus concentrations than highly susceptible accessions (24, 26, 27).

These tolerant materials have been utilized in breeding programs, and initial progenies appear promising (65, 129). Some progenies are highly tolerant to BGMV and produce 1,500 kg/ha under high disease pressure, as compared to yields of 1,000 (ICA-Pijao) and 650 (Turrialba 1) kg/ha for the progenitors. These progenies can produce 3,000 kg/ha in conditions where the virus is not a limiting factor to production.

Bean golden mosaic virus and its whitefly vector are able to survive on and infect various plant species, including beans. Integrated control measures can effectively reduce the incidence and severity of BGMV. These measures should consist of reducing vector populations by chemicals, eliminating alternative hosts, and using different planting dates combined with the development of agronomically acceptable cultivars with improved levels of tolerance or resistance.

Bean Chlorotic Mottle Virus

Introduction

Bean chlorotic mottle virus (BClMV), abutilon mosaic virus (AbMV), yellow dwarf mosaic virus and infectious chlorosis of Malvaceae have a similar symptomatology and are considered as a group in this section. Additional research is required to fully characterize these viruses to determine whether or not they are identical.

These viruses reportedly are widespread throughout Latin America, wherever the whitefly vector exists (4, 10, 12, 13, 14, 15, 16, 36, 38, 45, 78). They have been observed in Colombia, Mexico, Guatemala, El Salvador, Costa Rica, Cuba, Dominican Republic, Jamaica, Trinidad, Tobago, Venezuela, Ecuador, Peru, Bolivia and the United States. Often they are present in regions where bean golden mosaic virus and Rhynchosia mosaic virus exist. Their symptoms frequently are confused with those of BClMV and AbMV (27, 29, 31, 32, 36, 61, 97, 111, 113, 123).

Common names frequently used for bean chlorotic mottle virus and abutilon mosaic virus in Latin America include moteado clorótico del fríjol, enanismo amarillo, enanismo del fríjol, anao amarelo, clorosis infecciosa de las Malvaceas, and mosaico de Abutilon.

BClMV can cause 100% infection in susceptible cultivars but seldom is economically important. Its incidence normally is only 2-5% in Brazil (31). However, Costa (33) reported that BClMV caused 100% yield loss in each of five cultivars that he studied.

Fig. 9- Plant stunting and witches' broom produced by the bean chlorotic mottle virus.

This group of viruses has a wide host range which includes *Phaseolus vulgaris, P. lunatus, Abutilon hirtum* Sweet, *Althere rosea* (L.) Cav., *Bastardía viscosa* (L.) H.B.K., *Corchorus aestruans* L., *Gossypium barbadense* L., *G. hirsutum* L., *G. esculentum* Mill., *Hibiscus brasilensis* L., *H. esculentus* L., *Malva parviflora* L., *Malva silvestris* L., *Malvaviscus* sp., *Sida acuminata* D.C., *S. aggregata* Presl., *S. bradei* Ulbricht, *S. carpinifolia* L., *S. cardifolia* L., *S. glabra* Mill., *S. glomerata* Cav., *S. humilis* Cav., *S. micrantha* St. Hil., *S. procumbens* Sw., *S. rhombifolia* L., *S. urens* L., *Datura stramonium* L., *Nicandra physaloides* Gaertn., *Nicotiana glutinosa* L., *N. tabacum* L., *Solanum tuberosum* L., *Arachis hypogea* L., *Canavalia ensiformis* D.C., *Cyamopsis tetragonalobus* (L.) Taub., *Glycine max* (L.) Merr., *Lens culinaria* Medik., *L. esculenta* Moench., *Lupinus albus* L. and *Pisum sativum* L. (10, 12, 13, 14, 15, 20, 29, 30, 31, 39, 40, 45, 49, 55, 59, 61, 78, 81, 98, 110, 111, 112).

Symptomatology

BClMV and AbMV infection can cause a severe dwarfing of susceptible plants, accompanied by a high proliferation of buds and a bunchy or rosette type of plant development. If infection occurs in young plants, a witches' broom is produced and leaves often exhibit chlorotic mottling (Fig. 9). Chlorotic spots or mottled areas may be produced on leaves of tolerant cultivars or older susceptible plants (Fig. 10). These spots may be accompanied by a rugosing of leaves (Fig. 11). Severely affected plants

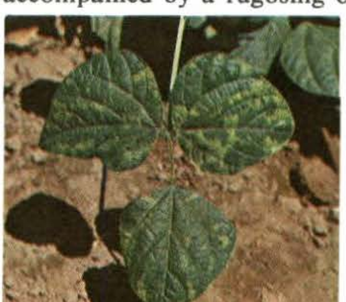

Fig. 10- Chlorotic mottle symptoms produced on leaves infected by BClMV.

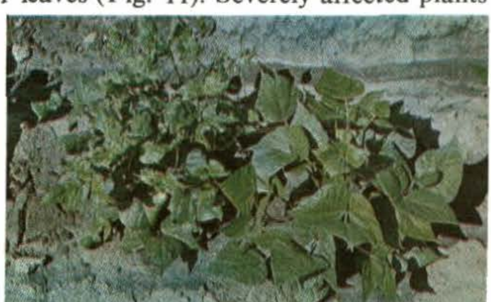

Fig. 11- Leaf rugosing suspected to be induced by BClMV.

Fig. 12- Chlorotic mottling induced by AbMV infection of *Pavonia sidaefolia*.

Fig. 13- Infectious chlorosis of Malvaceae symptoms induced in an infected *Malva* sp. plant.

produce few or no pods. Figure 12 illustrates AbMV symptoms produced in an infected *Pavonia* sp. plant, and Figure 13 illustrates symptoms of infectious chlorosis of Malvaceae in an infected *Malva* sp. plant.

Physical Properties

Sun (115) observed ultrathin cytoplasmic sections of *Abutilon striatum* var. *thompsonii* infected with AbMV and found spherical particles 80 nm in diameter. These particles consisted of an inner core 16 nm in diameter surrounded by an outer shell. Kitajima and Costa (81) observed isometric particles 20-25 nm in diameter in infected tissue of *Sida micrantha*. Additional studies are needed to compare these observations with BClMV isolated from other infected hosts including beans.

Costa and Carvalho (39, 40) determined that AbMV had a thermal inactivation point of 55° - 60°C, a final dilution end-point of 5-6, and retained its infectivity for 48-72 hours *in vitro* in water or sodium sulfide buffer.

Transmission and Epidemiology

Mechanical transmission of AbMV has been very difficult but has been accomplished by Costa and Carvalho (39, 40) from *Malva parviflora* and *Sida micrantha* to soybeans. The virus can be propagated in these species as well as in *Sida carpinifolia*. Bird *et al.* (20) was unable to transmit AbMV mechanically and had difficulties with its natural vector, *Bemisia tabaci* race *sidae*. Strain differences may exist within the virus and whiteflies.

Whiteflies have been demonstrated to transmit BClMV and AbMV to beans (10, 20, 29, 30, 31, 33, 36, 38, 56, 97, 113, 114). Bird *et al.* (20) showed that whiteflies could acquire the virus during a 15-20 minute feeding and retain their ability to transmit AbMV for seven days. Costa (33) was able to transmit AbMV easily from *Sida* sp. to beans but had difficulty transferring it from beans to beans via the whitefly.

Studies have not found BClMV or AbMV to be seed transmitted (20).

These viruses appear to have a wide host range, including many tropical weed species, which serve as inoculum sources from which whitefly populations acquire the virus and transmit it to beans. Epidemics of AbMV and BClMV also may occur in beans when large plantings of other susceptible crops such as soybeans and cotton, are planted nearby (27, 31, 61, 123).

Control

Very little research exists concerning control measures. However, Costa (31, 36) did not encounter any resistance within *Phaseolus vulgaris* in Brazil. Resistance was found in other species of *Phaseolus*, such as *P. angularis*, *P. aureus*, *P. calcaratus* and *P. trinervius* (31). The following *P. vulgaris* accessions were observed to be resistant to BClMV during a natural epidemic at CIAT: ICA - Tuí, Trujillo 7, Honduras 4, P.I. 307824 and P.I. 310739. Additional research is required to verify the resistance of these materials and the practicality of incorporating their resistance into agronomically desirable backgrounds.

Euphorbia Mosaic Virus

Introduction

Euphorbia mosaic virus (EMV) was isolated in 1950 from *Euphorbia prunifolia* Jacq. (37) and has since been observed in many species of *Euphorbia*. The virus has been detected in beans in Brazil but does not appear to be economically important. Common names frequently used for EMV in Latin America include mosaico de las Euforbiaceas and encarquilhamente da folha.

The host range of EMV includes *Euphorbia prunifolia*, *Datura stramonium*, *Lycopersicon esculentum*, *Nicandra physaloides*, *Nicotiana glutinosa*, *Canavalia ensiformis*, *Glycine max*, *Lens esculenta* and *Phaseolus vulgaris* (18, 20, 22, 31, 33, 36, 40).

Symptomatology

EMV or bean crumpling generally produces only local necrotic leaf lesions at the feeding sites of viruliferous whiteflies. Occasionally EMV may induce a systemic infection characterized by twisting or crumpling of leaves due to the unequal growth of green tissue surrounding the initial necrotic lesions. Abnormal development of auxillary buds also may occur, and plants are commonly stunted.

Physical Properties

Matyis *et al.* (86, 87) purified EMV partially and reported that it consists of identically-paired particles 25 nm in diameter and individual isometric particles which measure 12 - 13 nm in diameter. They determined that EMV belongs to the Geminivirus group.

Costa and Carvalho (39, 40) reported that EMV in sap has a thermal inactivation point of 55° - 60°C and retains its infectivity *in vitro* for more than 48 hours. Bird *et al.* (18) also report that EMV has a thermal inactivation point of 55° - 60°C but retains its infectivity *in vitro* less than 24 hours and has a dilution end point of 10^{-3}. Infectivity can be maintained in tissue dried in calcium chloride at 4°C for 12 weeks.

Transmission and Epidemiology

Euphorbia mosaic virus can be transmitted mechanically from *Euphorbia* sp. (Fig. 14) to *Datura* sp. at a rate of 31% and easily between *Datura* sp. (18, 22, 39, 40). Transmission from soybeans to soybeans is difficult. EMV is not seed-transmitted (20, 33).

Bemisia tabaci supply the natural mode of transmission, can acquire the virus during a 10-minute feeding period, but require a 20-minute period for transmission, and can retain their infectivity for 20 days (20, 31, 36, 37).

Euphorbia mosaic virus seldom is observed in bean fields unless there is a high incidence of whiteflies and infected *Euphorbia* spp. near or within the field.

Control

Very little research has been conducted on control measures for EMV, which is even less infectious to beans than BClMV or AbMV (31, 33, 36). However, plant resistance has been identified in accessions of *Phaseolus*

Fig. 14- Leaf wrinkling and chlorosis of an *Euphorbia* sp. plant infected with Euphorbia mosaic virus.

angularis, P. aureus, P. calcaratus and *P. trinervius*. Additional research is required to determine if resistance exists within *P. vulgaris* and is practical as a control measure.

Rhynchosia Mosaic Virus

Introduction

Rhynchosia mosaic virus (RMV) was isolated in Puerto Rico and produces symptoms similar to those reported for infected *Rhynchosia minima* in other tropical countries (11, 12, 13, 14, 15, 20, 84). Symptoms of RMV are similar to those caused by BClMV and AbMV. Research is required to determine the relationship between these viruses. Rhynchosia mosaic virus is transmitted by whiteflies but is not reported to cause economic problems.

The common name frequently used for Rhynchosia mosaic virus in Latin America is mosaico de la Rhynchosia.

The virus has a host range which includes *Salvia splendeus* Sellow, *Cajanus indicus* Spreng, *Canavalia ensifomis* (L.) D.C., *C. maritima* (Aubl.) Thou., *Crotalaria juncea* L., *Glycine max* (L.) Merrill, *Macroptilium lathyroides* (L.) Urban, *Pachyrrhizus erosus* (L.) Urban, *Phaseolus aborigeneus* Burk., *P. acutifolius* A. Gray. P. I. Wright, *P. acutifolius* A. Gray *latifolius, P. coccineus* L., *P. lunatus* L., *P. trichocarpus* C. Wright, *P. vulgaris* L., *Rhynchosia minima* DC, *R. reticulata* DC, *Vigna aconitifolia* (Jacq.) Marechal, *V. angularis* (Willd.) Ohwi and Ohashi, *Abelmoschus esculentus* (L.) Moendi, *Gossypium hirsutum* L., *Malachra capitata* L., *Oxalis berrelieri* L., *Nicotiana acuminata* Hook, *N. alata* Link and Otto, *N. bonariensis* Lehmann, *N. glutinosa* L., *N. nightiana* Goodspeed, *N. maritima* Wheeler, *N. paniculata* L.and *N. tabacum* L. (11, 20).

Symptomatology

Rhynchosia mosaic virus infection of beans causes symptoms such as leaf malformation, yellowing (Fig. 15), witches' broom and plant stunting.

Fig. 15- Bean leaves infected with Rhynchosia mosaic virus.

When infection occurs in young plants, symptoms consist of a proliferation of flowers and branches and little if any seed production (14).

The virus has not yet been purified to study its physical properties.

Transmission and Epidemiology

Mechanical transmission (18%) has been demonstrated by using buffers and the tobacco cultivar, Virginia 12, as source of inoculum (12, 20). Rhynchosia mosaic virus has not been found to be seed-transmitted (20).

The virus is easily transmitted by *Bemisia tabaci* (11, 20). Transmission can be achieved in less than 24 hours and the insect retains its infectivity for seven days. Apparently, the virus survives in infected weeds such as *Rhynchosia minima* which is widespread throughout the tropics.

Control

Very little research has been conducted into control measures for RMV. Glasshouse investigations in Puerto Rico (20), revealed that the bean cultivars La Vega (R19) and Santa Ana (selection from Masaya, Nicaragua) were tolerant to the virus and had a good level of resistance in the field.

Other Whitefly-Transmitted Viruses

Bird (9,20) reports that three viruses were capable of infecting beans under controlled conditions in Puerto Rico. They were Jatropha mosaic virus, isolated from *Jatropha gossypifolia* (L.) Pohl and transmitted by *Bemisia tabaci* race (biotype) *jatropha;* Merremia mosaic virus, isolated from *Merremia quinquefolia* Hall and transmitted by *Bemisia tabaci* race (biotype) *sidae;* and Jacquemontia mosaic virus, isolated from *Jacquemontia tamnifolia* Griseb and transmitted by *Bemisia tabaci* race (biotype) *sidae.*

This chapter has reviewed briefly some of the whitefly-transmitted viruses which are reported to infect beans under natural and artificial conditions. Much confusion exists between investigators as to virus identification and relationships (20, 33, 36, 41, 61, 76, 86). Additional research is required to elucidate this complex group of viruses and to study the variability which may exist within these viruses and their whitefly vectors.

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