Disease Transmission

Growers generally rely on whitefly suppression to manage disease incidence. This is not entirely satisfactory, however, and removal of virus-infected plants is often suggested to minimize within-field spread of viruses. Since whiteflies may transmit disease from one crop to another, or from weeds to crops, vegetation management is important. As noted above, reflective mulches have not produced economic benefits consistently. Mineral and vegetable oils inhibit virus transmission. Row covers or other physical barriers can substantially prevent disease transmission, but are often not practical.

► Whitefly Bioecology and Management
► Greenhouse Whitefly
► Sweetpotato and Silverleaf Whitefly

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Whitefly Bioecology and Management in Latin America

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Though some 1,200 whitefly (Hemiptera: Aleyrodidae) species have been described to date, only a few species are economically important agricultural pests. In Latin America (which for the purposes of this article includes Mexico, Central America, the Caribbean region and South America), less than a dozen whitefly species have historically caused economically-important damage to crops. The important species include *Aleurocanthus woglumi* (on citrus), *Aleurocybotus occiduus* (rice and sorghum), *Aleurodicus dispersus* (bananas), *Aleurodicus talamancensis* (bananas), *Aleurothrixus floccosus* (citrus, guava and other fruit trees), *Aleurotrachelus socialis* (cassava), *Bemisia tabaci* (many crops), *Bemisia tuberculata* (cassava), *Trialeurodes vaporariorum* (many crops), and *Trialeurodes variabilis* (cassava and papaya).

The most damaging and widespread whitefly species worldwide, and in Latin America, are *B. tabaci* and *T. vaporariorum*. The former species is by far the most important pest and vector of many plant viruses, particularly in the lowlands and mid-altitude (up to 1,200 m) valleys of the tropics. *Trialeurodes vaporariorum* is also a major pest of many crops in the tropical highlands (above 1,000 m of altitude) and temperate regions of the world, and is known to transmit several economically important plant viruses.

Damage and Economic Importance

All *B. tabaci* and *T. vaporariorum* life stages (eggs, nymphs and adults) are normally found on the underside of leaves. Crawlers emerging from eggs barely move from the point of hatching, after which they settle for the remainder of their lives, until the adult stage emerges.

Both nymphs and adults use their long mouthparts (stylets) to reach the phloem of the leaves and remove sap (rich in sugars and amino acids) that is continuously excreted. The sweet substance ("honeydew") covers the plant parts where the whiteflies are feeding, providing a suitable substrate for some superficial fungi known as "sooty molds." These fungi cover the leaves and other photosynthetic tissues of the affected plants, blocking sunlight. The sooty molds also reduce the quality of the produce, particularly in the case of cotton lint, which cannot be processed when covered by the honeydew and mycelium of the fungus.

In recent years, a new biotype ("B") of the whitefly *B. tabaci* appeared in Latin America. It is known to inject toxicogenic substances present in nymph's saliva that can induce physiological disorders such as uneven ripening of tomato, squash silverleaf, pumpkin white stem, white streaking in cole crops, as well as pod and stem blanching of snap beans and lettuce, respectively. Some authors have proposed that the new biotype is actually an entirely new species (*Bemisia argentifolii*), but this has not gained wide acceptance among entomologists (Fig. 49).

However, the main damage caused by *B. tabaci* is associated with its notable capacity to transmit over 200 different plant viruses, belonging for the most part to the genus *Begomovirus*, family *Geminiviridae*. *B. tabaci* also transmits viruses in other genera, namely, *Carlavirus*, *Crinivirus*, *Ipomovirus* and *Potyvirus*. These viruses affect many food and industrial crops, particularly in the tropical and sub-tropical regions of the world. *T. vaporariorum* has also gained some notoriety as a vector of some important plant viruses, particularly in sub-tropical and high-altitude tropical environments, but the number of these viruses is still low when compared to the number of viruses transmitted by *B. tabaci*. *T. vaporariorum* is the main vector of criniviruses (*Closteroviridae*).

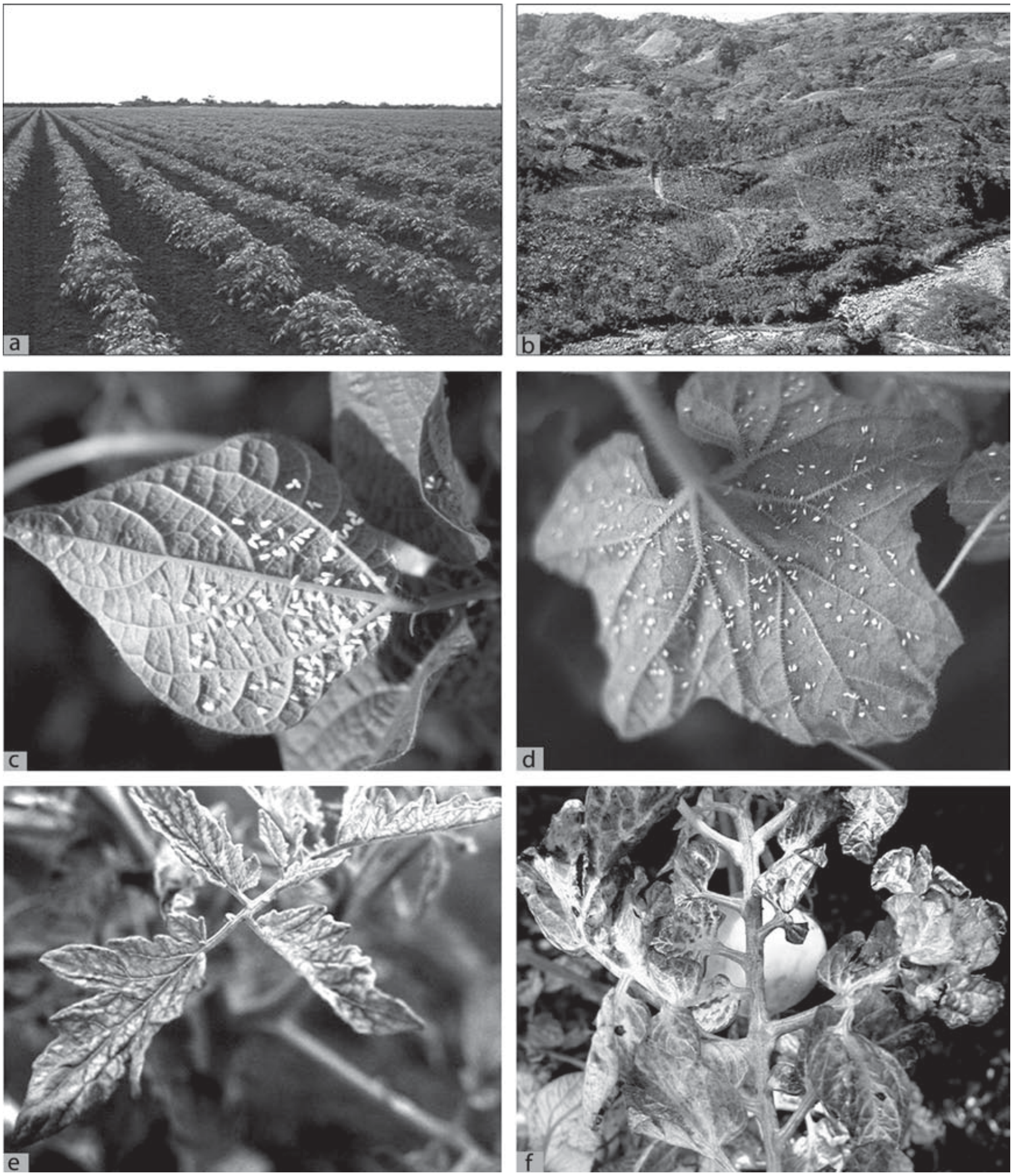
So far in Latin America, 35 crops (23 of them fully confirmed) have been reported as feeding and/or reproductive hosts of *B. tabaci*, including mainly annual but also perennial crops (see Table 5) in 14 plant families: Apocynaceae, Asteraceae, Caricaceae, Convolvulaceae, Cruciferae, Cucurbitaceae, Euphorbiaceae, Fabaceae, Malvaceae, Myrtaceae, Passifloraceae, Pedaliaceae, Solanaceae and Vitaceae. The principal hosts, considering their socioeconomic importance, area covered and damage levels, are tomato, common bean, melon, watermelon, cotton, bell pepper and hot peppers. *Trialeurodes vaporariorum* feeds on more than 250 plant species. The crops most affected by *T. vaporariorum* are dry and snap beans, tomato, peppers, cucumber, squash, eggplant, potato, pea (*Pisum sativum*), broad bean (*Vicia faba*), and cotton.

The feeding and/or reproductive performance of *B. tabaci* on a given host also depends on the particular biotype involved. For instance, in some Latin American countries where the "A" biotype still predominates, it does not colonize tomato to a significant extent, whereas huge numbers of eggs and nymphs are frequently observed on bell pepper. This situation is completely reversed in the case of the "B" biotype, which colonizes tomato, but does not lay eggs in most pepper cultivars.

Bemisia tabaci and *T. vaporariorum* also feed and/or breed on hundreds of wild plant species. Worldwide, *B. tabaci* has been observed on at least 500 plant species belonging to 74 families, but its full host range remains unknown both in Latin America and worldwide, and will certainly keep increasing due to the ability with which the "B" biotype adapts to new host plants. Despite its well-documented polyphagous nature, *B. tabaci* shows a distinct preference for members of certain families, such as Fabaceae, Asteraceae, Malvaceae, Solanaceae, Euphorbiaceae and Cucurbitaceae. *Trialeurodes vaporariorum* is mostly found on plant species in the Solanaceae, Fabaceae, and Cucurbitaceae.

Bioecological Characteristics

There are several biological and ecological characteristics of *B. tabaci* that can be important for its management in terms of assessing the risk of damage and the potential for successfully controlling it. Three key characteristics are discussed here: genetic plasticity reproductive potential and virus transmission.



Whitefly Bioecology and Management in Latin America, Figure 49 ***Top row*****, contrasts between current cropping systems in Latin America: a large tomato monoculture in Bahía, Brazil (a), and a "mosaic" of beans and vegetables interspersed between coffee and sugarcane plantations in Turrialba, Costa Rica (b) (Photos by Luko Hilje). Middle row, large whitefly populations: *T. vaporariorum* on common beans in Colombia (c), and *B. tabaci* on melons in Guanacaste, Costa Rica (d) (Photos by Luko Hilje and CIAT, respectively). Bottom row, plants affected by whitefly-borne viruses: tomato yellow mosaic virus (ToYMoV), transmitted by *B. tabaci* to tomatoes in Grecia, Costa Rica (e), and an undetermined crinivirus vectored by *T. vaporariorum* to tomatoes in Colombia (f) (Photos by Luko Hilje and CIAT, respectively).**

Whitefly Bioecology and Management in Latin America, Table 5 **Host crops of *Bemisia tabaci* reported to date in Latin America[a]**

Scientific name	Family	Common name
Abelmoschus (= Hibiscus) esculentus	Malvaceae	Okra
Capsicum annuum	Solanaceae	Bell pepper
Capsicum frutescens	Solanaceae	Hot pepper
Carica papaya	Caricaceae	Papaya
Citrullus lanatus	Cucurbitaceae	Watermelon
Cucumis melo	Cucurbitaceae	Melon
Cucumis sativus	Cucurbitaceae	Cucumber
Cucurbita argyrosperma	Cucurbitaceae	Pipián
Cucurbita maxima	Cucurbitaceae	Squash
Cucurbita moschata	Cucurbitaceae	Ayote
Cucurbita pepo	Cucurbitaceae	Squash
Fernaldia pandurata	Apocynaceae	Loroco
Glycine max	Fabaceae	Soybean
Gossypium hirsutum	Malvaceae	Cotton
Lycopersicon esculentum	Solanaceae	Tomato
Manihot esculenta	Euphorbiaceae	Cassava
Medicago sativa	Fabaceae	Alfalfa
Nicotiana tabacum	Solanaceae	Tobacco
Passiflora edulis f. flavicarpa	Passifloraceae	Passion fruit
Phaseolus acutifolius	Fabaceae	Tepary bean
Phaseolus vulgaris	Fabaceae	Common bean
Solanum melongena	Solanaceae	Eggplant
Vitis vinifera	Vitaceae	Grape
To be confirmed		
Arachis hypogaea	Fabaceae	Peanuts
Brassica oleracea var. capitata	Cruciferae	Cabbage
Brassica oleracea var. italica	Cruciferae	Broccoli
Brassica oleracea var. botrytis	Cruciferae	Cauliflower
Helianthus annuus	Asteraceae	Sunflower
Ipomoea batatas	Convolvulaceae	Sweet potato
Lactuca sativa	Asteraceae	Lettuce
Phaseolus lunatus	Fabaceae	Lima bean
Psidium guajava	Myrtaceae	Guava
Raphanus sativus	Cruciferae	Radish
Sesamum indicum	Pedaliaceae	Sesame
Solanum tuberosum	Solanaceae	Potato

[a]Based upon Anderson and Morales (2005) and Hilje (2003), but including only those crops recorded by either whitefly taxonomists or specialists working with molecular techniques. Crops to be confirmed include those which have been reported as hosts elsewhere and on which whiteflies closely resembling *B. tabaci* have been collected, but still requiring full confirmation.

Genetic Plasticity

The remarkable plasticity of *B. tabaci* makes its management extremely difficult. For instance, *B. tabaci* can rapidly develop resistance to insecticides, including novel ones, as has occurred in recent years with some neonicotinoids and insect growth regulators. Also, it has expanded its geographic range by adapting to higher altitudes and latitudes. *Bemisia tabaci* can be found at altitudes over 2,000 m in Costa Rica, which is unusual for this species. The altitudinal dissemination of *B. tabaci* is often aided by the movement of propagative material from the lowlands to the highlands.

Bemisia tabaci can also give rise to a series of races or biotypes that vary in their host-plant relationships, as well as in their ability to induce physiological disorders. The efficiency of transmission of plant viruses by *B. tabaci* also differs among biotypes, though the original biotypes were usually more efficient vectors. So far, some 23 biotypes have been detected worldwide by means of molecular and biochemical methods. The most widely distributed in Latin America is the new "B" biotype, followed by the original "A" biotype, as well as an undetermined number of regional biotypes (Table 6).

So far, the "A", "B" and "Q" are the only biotypes that have received some degree of attention in terms of understanding their life cycles, physiology, behavior, and host-plant relationships. Such studies are crucial, not just because of their academic value, but also due to their practical consequences. For instance, in contrast to the "A" biotype, the "B" biotype can feed or breed on cole crops (cabbage, cauliflower and broccoli), lettuce, citrus and papaya, and can successfully develop on tomato; its nymphs can induce the aforementioned syndromes on tomato, squash, cole crops and lettuce. The "B" biotype also has a higher (two-fold) fecundity, and is more cold-tolerant. Interestingly, some biotypes can coexist on the same plant species and even on the same plant, as it has been noticed in Guanacaste, Costa Rica, where individuals of the "A" and "B" biotypes have been collected along with other undescribed biotype on the same jalapeño pepper plants.

Trialeurodes vaporariorum is also capable of developing genetic resistance to insecticides, but it does not seem to exhibit the high genetic variability of *B. tabaci*. However, in highly disturbed and chemically contaminated agro-ecosystems, *T. vaporariorum* can attack an unusually large number of cultivated and wild plant species.

Reproductive Potential

This characteristic depends on the insect's fecundity, generation time, sex ratio, and longevity, but these parameters can vary depending on the biotype, temperature and relative humidity, as well as the quality and age of the host plant species or cultivar.

For *B. tabaci* raised under controlled conditions (25°C and 65% relative humidity) in Venezuela, average fecundity (number of eggs/female) was 194 (possibly corresponding to the "B" biotype); generation time (interval elapsing between two successive generations) was 42 days; sex ratio (females: males in the offspring) varied from 3:1 to 1:1, but females can show arrhenotokic parthenogenesis (unmated females can give rise to a 100% male offspring); and adult longevity typically ranges from 11 to 20 days. For *T. vaporariorum* raised at 23°C and 80% relative humidity in Brazil, average fecundity was 186 eggs; generation time was 23 days; sex ratio also varied; and adult longevity was about 24 days.

Tropical regions offer a unique agroecological environment for *B. tabaci* to fully express its reproductive potential. Temperature, rainfall and air humidity are normally much higher than in temperate areas, and photoperiod varies only slightly throughout the year. Since temperature is fairly constant but quite high, and insects are poikilothermic, *B. tabaci* can breed continuously, giving rise to very high densities and overlapping generations.

Optimal temperatures for *B. tabaci* development range between 30 and 33°C. At these temperatures,

Whitefly Bioecology and Management in Latin America, Table 6 Distribution of *Bemisia tabaci* biotypes in Latin America to date

Country	Region	Biotypes
Mexico	North	A, B
Guatemala	Central	A, B and others
Belice	Central	B
El Salvador	Central	A, B
Honduras	Central	A, B and others
Nicaragua	Central	B and others
Costa Rica	Central	A, B and others
Panama	Central	A, B
Cuba	Caribbean	B
Dominican Republic	Caribbean	A, B
Haiti	Caribbean	B
Puerto Rico	Caribbean	B
Jamaica	Caribbean	B
Colombia	South	A, B
Venezuela	South	A, B
Ecuador	South	A, B
Peru	South	A, B
Brazil	South	B
Bolivia	South	B
Chile	South	B (?)
Uruguay	South	?
Paraguay	South	?
Argentina	South	A, B and others

fecundity increases and generation time shortens, leading to very rapid population growth. Such temperature values are easily reached during the dry season, when thermal accumulation ("physiological time") is high. This is particularly true in irrigated, hot and dry areas devoted to export crops such as melons, watermelon and vegetables, where furrow or drip irrigation provides enough moisture for nymphs to complete their development. On the contrary, sprinkler irrigation, which mimics rainfall, has adverse effects on whitefly populations, due to dislodgment of adults from plants. There also are possible negative effects of increased relative humidity on the immature stages, or increased incidence of entomopathogenic fungi, associated with sprinkler irrigation.

Populations of *B. tabaci* are normally lower during the rainy season. Nevertheless, it is not unusual to observe tomato and bean fields 100% affected by whitefly-borne viruses, even during the rainy season. This typically occurs when farmers plant soon after the dry season and when whitefly populations are still high, or whenever the rainfall levels are lower than normal.

Trialeurodes vaporariorum is adapted to much cooler environments than *B. tabaci*, and is more characteristic of sub-tropical and temperate agro-ecosystems than true tropical environments.

However, this whitefly species causes total yield losses in several crops grown in the tropics at altitudes higher than 1,000 m, where the temperature is cool or cold and humidity can range from very dry to very humid within the year. *Trialeurodes vaporariorum* populations also increase rapidly during dry periods of the year.

Virus Transmission

In contrast to the majority of whitefly species, *B. tabaci* has the ability to acquire and transmit over 200 different viruses, mainly begomoviruses, which cause significant yield losses in important crops such as tomato, bell and hot peppers, beans, and various cucurbits including melon and squash. *Bemisia tabaci* can rapidly disseminate viruses in the field even when populations are not appreciable, and cause severe crop damage in susceptible plantings. Hence, economic thresholds are not recommended for whitefly vectors of plant viruses.

As expected due to the high levels of biodiversity inherent to the neotropics, there are many endemic whitefly-borne viruses yet to be discovered and named. In fact, any one of these crops may be affected by several types of viruses either in different countries or different areas within a given country, as it occurs with tomato, which is affected by at least 17 types of begomoviruses in America. Moreover, sometimes they appear in mixed infections, giving rise to complex synergistic interactions.

However, some of these native viruses could eventually be displaced by more competitive exotic viruses, as has already occurred in several countries with *Tomato yellow leaf curl virus* (TYLCV), an Old World virus that was accidentally introduced in the Caribbean Basin. TYLCV was first detected in the Dominican Republic, and then moved rapidly into Haiti and other Caribbean islands (Puerto Rico, Cuba, Bahamas, Jamaica and Guadeloupe). This virus then emerged in Florida, USA and in Yucatan, Mexico. So far, TYLCV has been managed through the use of virus-resistant tomato cultivars and novel insecticides. Curiously, TYLCV has not adapted well in Yucatan, Mexico. Nevertheless, TYLCV has caused millions of dollars worth of direct damage to tomato plantations in the Dominican Republic and Haiti, and considerable damage to the tomato paste industry of that island during the initial epidemics suffered in the early 1990s.

The higher degree of pathogenicity and virulence shown by exotic Old World viruses such as TYLCV may be related to their long-term association with mixed cropping systems and aggressive vectors, such as biotype "B" of *B. tabaci* in the Old World. The significant damage caused by TYLCV in the Dominican Republic may be also associated to the coincidental introduction of TYLCV and the "B" biotype in a country that was beginning to promote both traditional and non-traditional export crops, including common bean, tomato, melons, eggplant, peppers, and other susceptible crops. On the other hand, the arrival of TYLCV in other Caribbean islands and in Yucatan, has not caused a rapid displacement of the existing neotropical begomoviruses of tomato, probably because of the more traditional cropping systems in these latter locations.

It is important to note that these pathosystems often involve at least four components: *B. tabaci* biotypes, begomoviruses, crops, and whitefly and virus hosts. Each element is an important biological variable that, when combined, could give rise to unmanageable, severe outbreaks of highly damaging virus problems.

Northern Mexico, Guatemala and Brazil are examples of countries where the diversification of cropping systems, with a view to producing export crops, resulted in major pandemics of begomoviruses. Several crops were affected, and significant crop losses caused by the whitefly-transmitted viruses brought the diversification effort to a halt. For instance, the 1990s witnessed severe attacks of different begomoviruses in several crops grown for export in northern Mexico, including common bean, tomato, cucurbits, and peppers. In 2001, over 1,000 ha of melon were severely damaged in Zacapa, Guatemala, with unexpected high losses. Common bean, tomato and peppers were also severely attacked in the lowlands and mid-altitude valleys of southeastern Guatemala. In Brazil, a major campaign to promote high value horticultural crops for export in the mid-1990s met with a similar disastrous fate, resulting in loss of hundreds of thousands of hectares to whitefly-transmitted viruses.

Trialeurodes vaporariorum has gained notoriety as a vector of plant viruses only in the last two decades, particularly in temperate regions. However, this whitefly species has now been shown to transmit criniviruses in the tropical highlands of South America, affecting important crops such as potato and tomato.

Management Alternatives

Historically, insecticides have been the first line of defense against *B. tabaci* and *T. vaporariorum* in both their roles as direct pests and virus vectors. This pattern is seen not only in Latin America, but in most agricultural regions of the world. Unfortunately, the first insecticides used to control whiteflies were conventional, broad-spectrum products applied singly or, more often, in mixtures of organophosphates and pyrethroids, known as “cocktails.” These products soon failed to control these whitefly pests due to the outstanding genetic capacity that whiteflies have to develop resistance to insecticides of different nature. Farmers soon reacted to this situation by spraying three times a week, and even daily against these pests. Obviously, these insecticide applications were not a cost-effective approach, and increased production costs by at least 30%. For instance, in Guatemalan cotton fields, *B. tabaci* had developed resistance to 16 different insecticides by 1987, reaching resistance levels as high as 980X for biphenthrin and cyhalothrin, and over 2000X for quinalphos and deltamethrin.

In view of this situation, new chemistries such as neonicotinoids (e.g., imidacloprid, acetamiprid, thiamethoxam, nitenpyram and thiacloprid) and insect growth regulators (e.g., buprofezin and pyriproxyfen), were developed and widely used despite their higher prices. Unfortunately, insecticide abuse (excessive number of applications) and misuse (active ingredient diluted with other products) still occurs in several Latin American countries, which along with the lack of complementary IPM programs (like the ones so far implemented in Israel, southwestern USA and elsewhere) pose a high risk for the emergence of new whitefly populations possessing resistance to the new compounds.

Despite the presence of many native natural enemies (parasitoids, predators and entomopathogenic fungi) of *B. tabaci* and *T. vaporariorum* in Latin America, including at least ten different species of the parasitoid *Eretmocerus*, and two species of *Encarsia*, biological control agents have not been widely used or observed to be effective control agents in whitefly-affected agricultural regions. The explanation for this observation is the slow action of biological control agents, as compared to insecticides. In general terms, biological control can only be effective in areas where neither insecticide abuse nor viruses vectored by whiteflies occur.

Alternative whitefly control strategies are available and can be highly effective when used properly. Some of these IPM practices include:

Phytosanitary Campaigns

In past years, successful whitefly control measures were implemented in the Dominican Republic, Mexico and Cuba, supported by legal measures that required the strong participation of the affected farmers. These campaigns were mostly based on the implementation of a susceptible or host crop-free period.

In the early 1990s, the processing tomato industry in the Azua Valley and other production areas of the Dominican Republic were critically affected by production drops due to the introduction of TYLCV. The cultivated area in the Azua Valley dropped from 8,805 ha in 1989 to 3,729 has in 1993, whereas yield decreased from 21.6 to 11.3 MT/ha within the same period. This situation forced the nascent tomato paste industry in the Dominican Republic to import tomato paste from Chile. The enforcement of legal measures that banned cultivation of *B. tabaci* reproductive hosts up to 90 days before the main tomato growing season, along with crop rotations with non-whitefly hosts, such as sorghum, significantly diminished begomovirus incidence in Azua. These legal measures were complemented by planting of TYLCV-tolerant hybrids and a judicious insecticide use scheme, which allowed the tomato industry in the Dominican Republic not only to subsist, but also to increase the area planted to 8,940 ha and yields to 30.4 t/ha.

Host Plant Resistance

In the 1980s, a major crop improvement project was launched by the PROFRIJOL network to incorporate genetic resistance to whitefly-transmitted viruses affecting common bean in Latin America. This was conducted under the coordination of the International Centre for Tropical Agriculture (CIAT), in Colombia. Despite the termination of this successful project due to the economic crises that have affected national and international agricultural research institutions in Latin America, some international projects (such as CRSP-USAID) continue to generate begomovirus-resistant common bean varieties in Central America from its main pilot site at the Pan-American Agricultural School (Zamorano) in Honduras.

REDCAHOR was another network created in the early 1990s to improve horticultural crops in Central America, but it was short lived. In past years, only some semi-commercial initiatives in Guatemala (University of San Carlos and University of Wisconsin), and the Tropical Whitefly IPM Project coordinated by CIAT, are developing tomato hybrids and varieties possessing resistance to whitefly-borne begomoviruses. The most advanced tomato breeding project in Latin America is now conducted by the Horticultural Research Institute "Liliana Dimitrova" in Havana, Cuba.

Physical Exclusion

Because young plants are more susceptible to damage by whiteflies and whitefly-transmitted viruses, seedlings must be protected in seedbeds before transplanting in the field (e.g., tomato and pepper seedlings). Seedlings are usually protected in insect-proof screenhouses or glasshouses, or at least with insect-proof fleece placed over the seedbeds. This practice has been increasingly accepted over the years, thanks to a few entrepreneurs who produce virus-free seedlings for sale. Also, some farmers use micro-tunnels to produce their own seedlings.

Among the many mesh sizes commercially available, it has been shown that a 50-mesh screen effectively stops *B. tabaci* adult entrance into protected structures, while allowing adequate airflow through the screening to favor seedling development. However, structures constructed with screens or plastics treated with an absorbing additive that blocks a portion of the ultraviolet light spectrum, and which hinders the ability of *B. tabaci* to locate plants, are still uncommon due to the high cost of this novel technology. In Israel and elsewhere, it has been shown that greenhouses protected with these ultraviolet-blocking materials have lower whitefly populations and less virus incidence, in comparison to similar materials that transmit more ultraviolet light.

Another approach that has gained acceptance, especially in Mexico and Guatemala, is the use of "floating" row covers to reduce the spread of whitefly-transmitted viruses. With this technology, field-sown or transplanted seedlings can be protected in their early stages of development by temporarily covering them with lightweight materials, such as spun-bonded polyester, and there is no need for any supporting structure.

The cover remains over the plants until it is necessary to remove it to allow bee pollination and other cultural practices.

Mulching

Mulches are used for certain crops in order to control weeds or to avoid contact of delicate fruits with the soil. However, some mulches have been shown to reduce the number of whiteflies, and incidence of whitefly-transmitted viruses in certain crops. Aluminum, silver or metallic mulches have proven to be most effective in reducing *B. tabaci* adults on plants. The most important factor is not the color of the mulch, but the intensity with which the light is reflected off the mulched soil. The main constraints to the adoption of this method of whitefly control include the high cost and the environmental impact of discarded plastics.

An environmentally-friendly and cost-effective alternative to mulching is the use of ground covers, which have been successfully tested in commercial tomato fields in Costa Rica. Instead of repelling whiteflies, they mask the young tomato plants from viruliferous whiteflies. Among several promising candidate plant species, coriander (*Coriandrum sativum*, Apiaceae) stood out, as farmers can harvest it 35 days after planting, after the critical period of tomato plant susceptibility is over. This technique warrants more attention, as it is particularly well suited for small farms.

Chemical Repellents

Any compound capable of keeping whiteflies away from susceptible plants reduces the possibility of virus inoculation and subsequent disease expression. Protection can be achieved either by feeding deterrent (acting after contact) or repellent (acting at a distance, as vapors) substances.

It has been shown that in proper doses, both cooking and mineral oils can deter *B. tabaci* without causing phytotoxicity, but these are not widely used by farmers. Moreover, in Costa Rica, after testing approximately 70 hydroalcoholic extracts from plants, deterrence of whiteflies was detected in the following ten species: worm-seed (*Chenopodium ambrosiodes*, Chenopodiaceae), sword bean (*Canavalia ensiformis*, Fabaceae), "chile muelo" (*Drymis granatensis*, Winteraceae), bitterwood (*Quassia amara*, Simaroubaceae), mother of cocoa (*Gliricidia sepium*, Fabaceae), neem (*Azadirachta indica*, Meliaceae), wild "tacaco" (*Sechium pittieri*, Cucurbitaceae), "sorosí" (*Momordica charantia*, Cucurbitaceae), fish bean (*Tephrosia vogelii*, Fabaceae), and wild sunflower (*Tithonia diversifolia*, Asteraceae). Some of them are currently receiving additional research.

Volatile substances of botanical origin, mainly alcohols and aldehydes, can repel whiteflies. Repellency has been shown to exist for cinnamaldehyde, perialdehyde, 1-hexanal and Z-3-hexen-1-ol. These compounds have been further tested by enclosing them in controlled-release dispensers to avoid phytotoxicity and increase their life span both in field crops and commercial greenhouses.

Concluding Remarks

Whereas the knowledge on whitefly-related crop production problems has significantly increased in the past two decades, *B. tabaci* and *T. vaporariorum* are still major pests and vectors of plant viruses that affect many industrial and food crops in Latin America. The main reason for the apparent difficulty in controlling these pests has been the economic crises that drastically reduced crop production-oriented research and crop improvement projects in Latin America. Technical assistance or, rather, the lack of it, is also another major cause of the continuous emergence of insecticide-resistant populations of *B. tabaci* and *T. vaporariorum* in Latin America. In the absence of resistant varieties and technical assistance, farmers do not have alternatives different from chemical control. Insecticide abuse soon leads to the elimination of the natural enemies of whiteflies, and emergence of insecticide-resistant whiteflies.

Also, a major factor that have contributed to the existing escalation in the number of whitefly biotypes and whitefly-borne viruses has been the diversification of the traditional cropping systems in Latin America. Promotion of mixed cropping systems that include both traditional and non-traditional export crops provides continuous food for whitefly pests year round. In addition to the continuous availability of plants suitable for whitefly survival, the plasticity of begomoviruses, and the ease with which they form genetic recombinants, are also notable factors driving the epidemics of old and new begomoviruses in many commercial crops grown for local consumption or export in Latin America. Consequently, technology generation and transfer efforts should be reconsidered and strengthened in Latin America, particularly in view of the challenge presented by the unavoidable integration of Latin American agricultural markets into a highly competitive globalized world.

► Greenhouse Whitefly
► Sweetpotato and Silverleaf Whiteflies
► Whiteflies
► Plant Viruses and Insects
► Transmission of Plant Diseases by Insects

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White Grubs, *Phyllophaga*, and Others (Coleoptera: Scarabaeidae)

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The whitish, soil-dwelling larvae of scarab beetle species are called white grubs. Traditionally, white grubs were considered to be members of the genus *Phyllophaga*, but increasingly the larvae of other members of the family Scarabaeidae such as *Anomala*, *Aphodius, Ataenius*, *Cyclocephala*, *Exomala*, *Polyphylla*, *Popilla*, *Rhizotrogus*, and other are included in this general term because they have a very similar appearance and biology.

Life History

The life cycle of the various species ranges from 1 to 4 years, although in the *Phyllophaga* species it is 2–4 years, with the 3-year life cycle most frequent. Duration of the life cycle is often related to latitude.