Bemisia Tabaci (the Sweet Potato Whitefly)

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A. The history of the pest

It is useful to consider the history of this homopteran pest in three phases.

Phase 1: Local outbreaks

There are descriptions of *Bemisia tabaci* from Greece in 1889, but it probably originated in Pakistan or Western India. Records of outbreaks from India exist from the early years of this century. Since 1927, *B. tabaci* has caused severe problems on vegetables in Palestine, and then in Israel, but until about 1968-9 it was only a pest of local significance. *B. tabaci* caused mainly two types of damage: (1) direct damage by feeding on the plants, and (2) transmission of plant viruses.

Phase 2: A worldwide cotton pest

In the late 1960s things started to change. *B. tabaci* became a very serious problem in the Sudan where the cotton industry suffered badly from sticky lint caused by the honeydew secreted by the insect. Early in 1970 the Sudanese had problems selling their cotton on account of its stickiness. Heavy outbreaks occurred in Turkey in 1973 and in 1976 in Israel. Very large numbers of *B. tabaci* caused heavy damage, and the means formerly known to control it no longer seemed to work any more. In 1981 the same thing happened in California on cotton, but this time lettuce plants were also attacked. *B. tabaci* grew on cotton, then landed on lettuce when cotton was defoliated around September, and although the whitefly does not reproduce well on lettuce, it transmitted Lettuce Infectious Yellowing Virus, which caused heavy losses.

Phase 3: Proliferation of new biotypes (type B or silverleaf whitefly)

The third phase of the history started in 1986 when heavy infestations occurred in Florida. In this case, Poinsettias and Hibiscus were severely attacked. In a short time the same problem turned up in California and it was traced to certain plants shipped there from Florida. No internal quarantine existed because at that time the *B. tabaci* occurring in Florida was not recognised as being any different from that in California (see below). Within a short period it moved (on greenhouse cultures) to many parts of the USA and later to the Caribbean and Mexico as well as South America. *B. tabaci* (strain affiliation unknown) has also invaded urkmenistan, (which used to be one of the Soviet Union Asian Republics) in 1985-87, as well as Japan. Thus, within 10 to 15 years what was a local problem has extended to become a global pest in most tropical and subtropical climates.

B. Biotypes of *Bemisia tabaci*

It is generally accepted that *B. tabaci* biotype B, which was found and typified in Florida and since then has shown up in many other places, differs considerably from the biotype that was previously known from California, and now designated as biotype A. Moreover, recent work suggested that 'B' may be a different species altogether. Molecular work done in the UK and the USA indicates that biotype B has invaded most of the world and is the dominant species in many countries. In addition to biotypes A and B, one can distinguish numerous additional types in various countries. In general, the methodology involved in *B. tabaci* biotype determination can be classified as follows:

(a) A single *B. tabaci* individual can be run through an electrophoretic plate to test for enzymatic differences. The only enzymes where meaningful differences have been found are the esterases. The different bands that show up on the electrophoretic gel were compared for *B. tabaci* collected in Israel ten years ago to those found in California, Florida (post-1986) and Kenya. All were distinctively different from each other. In Colombia we found four different strains, one for each valley between the mountain ranges of that country. A modification of the electrophoretic method, called iso-electric focusing, allows for comparing between individuals using more enzymatic patterns. This method was used to suggest that biotype B may constitute a distinct species.

(b) The insect can be tested for various biological parameters, such as longevity, flight behaviour and fecundity, and con-specificity can be tested through mating experiments. In order to do this it is very important to standardise techniques and methods, with both test groups being kept in the same place. This has been done for biotypes A and B in cultures in Britain, California and Arizona. The understandable reluctance of scientists to introduce questionable strains of this pest into their country greatly limits the use of this method. Some of the results of the biological tests include the findings that biotypes A and B differ in the amount of eggs they lay and their speed of development, and the two biotypes have great difficulty mating together.

(c) Host range: in the CABI literature review *B. tabaci* has a host range that is practically unlimited; between 500 and 700 plant species. When the host range reaches this level, the number of species affected becomes immaterial - there are probably plenty more hosts that have yet to be discovered. To be classified as a host means only that at least one insect has been found growing from egg to maturity on it. There is a world of difference between classifying plants as hosts and stating that *B. tabaci* is an agricultural pest. Thus, there are records of *B. tabaci* being in the Caribbean for many years. But this only means that it was able to reproduce successfully on plants in this region, but not necessarily that it was a pest.

We can observe different host ranges that may be typical to different biotypes. However the distinction is rarely absolute, as for example in the case of cassava, a root crop introduced into Africa and Asia from South America that has now become a staple crop for millions of people. In Africa, cassava is heavily attacked by *B. tabaci*, which directly affects yield and also transmits a mosaic virus which causes severe problems. This is not a problem in South America, however, where *B. tabaci* is not a serious pest of cassava. This is an example of host range inconsistencies, caused perhaps by strain differences.

Similarly *B. tabaci* was not known historically as a pest of crucifers. Nowadays, however, *B. tabaci* infestations on broccoli are a serious problem in California. The Imperial Valley is a major agricultural area where farmers grow cotton in the summer, broccoli in the autumn and lettuce later on. Before *B. tabaci* attacked crucifers the farmers left a gap between planting cotton and lettuce. This was sufficient to allow the whitefly populations to die down, since the pest cannot survive in the hot temperatures (40°C to 45°C) encountered in the Imperial Valley during that season, without suitable host plants. Now that broccoli is also attacked, they have a severe problem with whitefly, especially with virus transmission to the lettuce.

We mentioned previously the differences in esterases between the original Israeli whitefly and samples from Florida and California. Recently, however, the Israeli *B. tabaci* has begun to attack broccoli and other crucifers, and it has been shown by scientists in Britain that the Israeli strain now has the same characteristics as strain B. In addition, some experiments conducted in the United States Department of Agriculture laboratory in Salinas show that the esterase pattern of the Israeli *B. tabaci* is now similar to strain B.

Therefore, host range can now be used as a criterion for separation of strains, albeit a flexible one. One must always remember that when there are millions of pest individuals looking for food, there are very strong selection pressures to vary or change host range. With enough pressure, *B. tabaci* may manage to overcome some of the allelochemicals that might be discouraging attack. This probably occurs with relative ease in a species whose records show that it may have a very extensive host plant range. The overall picture is of different *B. tabaci* strains at different times and places, but this is no more than a convenient way to describe the *status quo* and is not an absolute means of classification. There will probably always be questions that can not be reconciled by strain testing. For example, the B strain in Florida is a pest of Hibiscus but in Israel it does not touch Hibiscus (at least not at the moment) - just to remind us that the host range is flexible.

C. Climatic factors

Bemisia tabaci is a typical warm climate insect pest - it does best between 25°C and 32°C. In laboratory experiments we have shown that it cannot survive over 34°C. This does not mean that when ambient temperatures exceed 35°C it will die out; indeed, *B. tabaci* is a serious pest in the Sudan and Egypt where summer temperatures reach 40°C and above. This is possibly due to the microclimate that surrounds the plant that is lower than the ambient temperature. In subtropical climates found in, for example, Israel and California, there are dramatic declines in whitefly populations caused by cooler temperatures, though infestations may continue to be severe on protected crops in greenhouses. Therefore, care is needed when comparing control strategies between countries or regions because climates can be so very different. A strategy unit might work well at a certain time of the year in Israel, but may not work in the Caribbean because of climatic differences.

B. *tabaci* does not do well in high humidities (above 65-70 per cent Relative Humidity) or extremely low humidities (below 20 to 25 per cent RH). In Israel, for example, when humidity is low (between May and July for one or two days each month, there can be dry winds with 15 per cent RH or less) the population drops to almost zero. At the other extreme, under rain forest conditions, B. *tabaci* does not do well and it is usually not a pest in such climates.

D. Biology

Eggs are laid on the underside of the leaf - preferentially along the veins. The female customarily sticks her mouth-parts into the leaf and starts ovipositing. With her stylet remaining in the leaf she rotates a little so that the eggs are laid in the pattern of a semi-circle or even a complete circle. Eggs hatch into crawlers which start to move around, but unlike scale insects they do not leave the leaf on which they have hatched. After a while they settle, stick their mouth-parts into the leaf and start developing into the 2nd, 3rd and 4th instars, and then into the a pupa, which is actually a continuation of the 4th instar. The adult emerges from the pupa through a T-shaped opening in the dorsal integument (parasitoids make a round hole when emerging).

Males are somewhat smaller than females. Usually the largest number of adult B. *tabaci* are found on the youngest growing parts of the plant, and these are normally the areas of the plant bearing most eggs and young immatures. Eggs are laid on the young growth and it takes approximately 20 days (the shortest development is about 14 days at about 30°C) for development to the adult stage. During this time, the plant keeps on growing, often very fast, so that the pupae are usually found lower on the plant than the eggs. Once they emerge, the adults may stay on the leaf for between 1 to 3 days and at the same time they may also deposit a few eggs on that original leaf. However, adult females often look for a more suitable place to oviposit, and so they start moving upwards to younger leaves or move to a different plant.

Moving to a different plant is a process still not completely understood, but some things are clear. In certain conditions, it may be that the plants are disturbed or over-populated and the whiteflies take flight to neighbouring plants or straight up into the air. They are very light insects and may be thought of more or less as aerial plankton rather than active flyers. They have very limited powers to move against prevailing air currents. They can be found 6-8 metres or higher in the air, sometimes in vast numbers. When they want to land, we presume that they spot a suitable place, fold their wings and plummet downwards towards the chosen place. If we monitor the fallout of whiteflies in a heavily infested area by placing a small yellow board on the ground (whiteflies are extremely attracted to the colour yellow) we find that the majority show up around 09.00 am. During heavy infestations as many as 100 B. *tabaci* may land each minute on a 16 x 20 cm board. Roughly 80 per cent of landings occur between 06.00 and 10.00 am.

B. *tabaci* prefer to land as close to the ground as possible. As many as 10 times more may be caught in a yellow trap at ground level as compared with 1m above the ground.

It would be instructive to know to what extent B. *tabaci* are able to choose their desired landing spot, and whether they can differentiate among the different crops such as melon, cassava or cotton. Experiments have shown that whereas they may be able to distinguish vegetation from bare earth, they cannot distinguish between a very attractive host, for example, melon, and a less attractive one such as cotton. Discrimination will occur only after they have landed on the plant when they decide, often after probing it, whether to stay or to move on. This behavioural pattern is the same for both the greenhouse whitefly and B. *tabaci* and indicates that whiteflies do not know what they are landing on. This trait is used to control for whiteflies - by mulching (see below). This inability to discriminate before landing is also exploited in the design of the whitefly trap (see below).

In B. *tabaci*, sex determination is similar to bees: males are haploid and females diploid. Thus a population can start even if only one female survives quarantine in a shipment to another country. If there is one female on a leaf in that shipment, perhaps in the pupal stage, and she survives to the adult stage, she will lay male eggs (because she is unfertilised) but she may live long enough to subsequently mate with her male offspring and thereby produce females. The sex ratio fluctuates around 50 per cent. In sub-tropical climates there is a preponderance of females in the early summer (about 60-70 per cent) and the summer will end with about 40 per cent females. The sex ratio variation is probably not of great significance for control in the field because there are always sufficient males and females around for the population to continue.

One of the important and unpleasant features of whiteflies is the secretion of honeydew. This is an important feature because honeydew makes the product (e.g., cotton lint or aubergine fruits) sticky and causes sooty moulds to grow. The honeydew of whiteflies differs from that of aphids, and its attraction to ants is much lower. For example, in laboratory whitefly cultures there are very few problems with ants. All instars secrete honeydew except the pupa, the late instars producing the most.

A final point on the biology of *B. tabaci* in relation to control strategy. At harvest time the whitefly population will quite often be extensive. It is usually not harmed by the harvesting process, and being deprived of the harvested crop, it will migrate to other crops in quest of food. This has advantages and disadvantages: if the whitefly population in the original crop shows heavy parasitism on one crop crucifers, we should consider what we do with the harvest residues so that the parasitoids go on working for us on the new crop. On the other hand if there are relatively few parasitoids we should think carefully about reducing a potential source of infestation for following crops.

E. Damage

Bemisia tabaci causes several types of damage.

1. Direct damage by sucking the sap

For crops like cotton or vegetables which are often damaged by various viruses, and may have sooty mould and honeydew stickiness problems, we often tend to ignore the direct damage caused through the loss of nutrients. Recently it has been shown that whitefly feeding causes direct damage to various characteristics of the cotton crop, including fineness of the lint, strength of the cotton fibre and its length.

On squashes, the whitefly feed on the leaves and cause separation of the epidermis of the leaf from the parenchymal layer. Air enters and causes a characteristic silvering, firstly on the veins. On an infested leaf the green leaf tissue can be seen with whitish veins in between. This is a characteristic feature, and is different from silvering that may be caused by thrips, for instance. It seems that no virus is associated with this phenomenon. Silvering will only occur on leaves which were on the plant while *B. tabaci* was feeding on it. The symptoms will not spread from leaf to leaf, and once the whiteflies are removed, new leaves will not show silvering. Although it is damaging, the losses caused are by no means as devastating as the tomato mosaic virus, for example.

2. Honeydew and sooty mould problem

The main damage is to cotton lint, with costs running into millions of dollars. Some damage occurs to vegetables such as aubergines or melons and cantaloupes.

3. Viruses

Mosaic viruses may cause symptoms such as yellowing, curling or blackened leaves, loss of fruiting capacity or deformed fruit. Plant tops may be bunchy and small. Tomato mosaic virus is a particularly severe virus problem which may cause fruit loss through failure to produce fruit altogether, fruit rotting, or alternate green (unripe) and red patches on the developing fruit which make it unmarketable, all depending upon the age at which the plant is attacked.

The key to virus control on tomatoes is to delay attack until the fruits start to set. After this, even though the plant may suffer, some ripe marketable crop will still be obtained. One way to do this is by using screens (see below). A second way is to exploit the fact that the tomato virus develops mainly in tomato plants and only rarely has alternate hosts. Therefore, strict sanitation can greatly limit the spread of the disease.

There are many other viruses transmitted by *B. tabaci*. In fact, it transmits over 20 different viruses, which probably is the largest number of viruses transmitted by any one insect in the world. Therefore, it is important to remember that this insect is very capable of picking up viruses from the environment and introducing them into the crop plants, and that it does so very efficiently. This is probably what happened with the cassava mosaic which originated in Africa, because the disease does not occur in South America, where the cassava plants originated.

4. Irregular ripening (in tomatoes)

This is a disorder caused by a physiological response of the plant to heavy attack of whitefly adults during fruit set, producing alternate stripes of white and red on the ripening fruit. Irregular ripening is rather easier to control than a virus problem, because it occurs only when whitefly populations are very high during fruit set.

B. tabaci strain B is somewhat less proficient in virus transmission but is a much more devastating insect as far as direct damage, irregular ripening and squash leaf silvering are concerned. In the laboratory, it lays more eggs, develops faster and produces much more honeydew on the plant than strain A. The Imperial Valley recently lost all its vegetable production (at a cost of around $200 million) because the vegetables were directly killed by strain B. The plants were killed when they were between one week and one month old. In July 1992, farmers in the region had to plough under their cotton because *B. tabaci* was killing the cotton plants through direct feeding.

F. Biological control

There are many parasitoids and predators associated with *B. tabaci* (see Tables 4.1 and 4.2 of CABI's literature survey of *B. tabaci*) but the mere existence of many known natural enemies does not necessarily mean easy or efficient biological control. Nevertheless, this large complex of potential control agents is there to be drawn upon and studied to determine what effect they are having and how they might best be employed for whitefly control.

Parasitoids: A number of genera of parasitoids attack whiteflies. The most important are *Encarsia* and *Eretmocerus*, both of which include species capable of controlling whiteflies under certain circumstances. The third genus is *Amitus*, which was not known to include parasitoids of *B. tabaci* until recently, when it was reared on whitefly in the Caribbean and South America. Since *B. tabaci* did not originate in the Caribbean or South America, this *Amitus* sp must have moved onto *B. tabaci* from a local indigenous whitefly. For various reasons *Amitus* does not appear to be a very promising control agent for *B. Tabaci* *Encarsia* and *Eretmocerus* have distinctly different host relations. *Eretmocerus* females, either virgin or mated, will always attack unparasitised whitefly nymphs. Virgins will lay male producing eggs and mated females will lay either female or male eggs. *Encarsia* species, on the other hand, exhibit heteronomous progeny development where the female producing eggs will develop like those of *Eretmocerus* on whitefly nymphs. However, the males are not parasitic on whitefly, but instead are usually parasitoids of parasitic hymenoptera. Thus, the *Encarsia* female (whether mated or not), wanting to lay a male egg, will lay it in a whitefly already parasitised by a hymenopteran. Her male offspring will therefore develop at the expense of the female larva of a hymenopteran which is inside a whitefly nymph. This is a complex life history, and there are debates about its suitability in biological control. However, there have been good results using *Encarsia* as a control agent for whitefly species, including *B. tabaci*. *Encarsia* spp parasitise both whitefly and diaspid scales. In contrast, all members of the genus *Eretmocerus* are exclusively parasitoids of whiteflies. All of the known females of *Eretmocerus* are yellow; they have a very large club on their antenna and most have green eyes when alive. These features make it relatively simple to pick out individuals from this genus following their emergence from whiteflies.

Encarsia lay their eggs inside the whitefly nymph (endoparasitoid). The *Eretmocerus* female on the other hand, finds the whitefly, climbs onto it, examines it and then gets off and sticks the eggs between the whitefly and the leaf, where the egg remains for about three days. The larva then hatches, and through a complex sequence of events, kills the host.

A useful way to tell if a whitefly has been attacked by *Encarsia* or *Eretmocerus* is as follows: *Encarsia* deposits a meconium, or faecal packet before pupating. This remains within the empty host integument. Immature *Eretmocerus*, on the other hand, do not deposit any faeces at all. Thus, if faecal deposits accompany the parasitised host, then the parasite is *Encarsia*. The absence of faecal deposits means that the parasite is *Eretmocerus*. Furthermore, *Eretmocerus* will always leave an empty yellowish-white host, whereas some *Encarsia*, such as *Encarsia transvena*, may leave a black pupal sac. Such simple diagnostic features are useful at the field level to determine events throughout the season.

All the experiments conducted so far have failed to show direct attraction of an infested leaf to parasitoids. The situation known to occur in various parasitoid species, as in braconids that attack lepidopterous larvae, is that they find the host by following kairomone trails liberated by the feeding host. In the whitefly, however, experiments have so far failed to show that there is such an attraction. Once the parasitoids have found a whitefly, however, the presence of honeydew will act as an arrestant to reduce the tendency of the parasitoid to take off again and look for a parasitoid. A heavily infested leaf may therefore keep more parasitoids for a longer time, but it will not attract more parasitoids to the leaf than a lightly infested leaf.

Predators: It is difficult to assess exactly how much damage is caused to whitefly populations by predators, since their activity is much harder to follow than parasitoids. They are often not present on the plant for much of the day and what and how much they ate cannot be determined. Traditionally, success with whitefly parasitoids has been sometimes spectacular, but not with predators. Some coccinellids are important predators of whitefly, some almost specifically so. Whitefly predators may belong to a number of insect orders, including coccinellids lacewings (Neuroptera), predatory heteroptera, flies, and predaceous mites. The coccinellids that feed on whitefly do not belong to the same group as the large predators that feed on aphids, but are much smaller, with some belonging to the genera *Scymnus* and *Delphastus*. Neuroptera may be common and, at times, can be important predators of whitefly. Of the bugs, there are mainly mirids and anthocorids that are known to attack whiteflies. There are also whitefly predators that belong to the Diptera and to the Acarina. Predators behave differently under laboratory as compared to field conditions. Specificity can be a problem. Even predators reared on whitefly in the laboratory may not, when released, look for and destroy the whitefly, but may show preference for another host.

We have evidence that lacewings (*Chrysoperla* spp) have become adapted to feed on whitefly. In laboratory tests conducted in 1978-79, we had great difficulty in getting lacewings to feed on *B. tabaci*. Now, however, the lacewings feed and develop readily on whitefly. In Israel, some authorities claim that the lack of problems with whitefly on cotton is largely due to the action of predatory mites.

Parasitoids vs predators: Parasitoids may not be efficient when they get to a leaf that is too heavily infested with whiteflies, as the leaf becomes gummed up with honeydew (and full of exuvia and other matter) which make it hard to climb on. Therefore, it takes the parasitoid a long time to get from one whitefly to the other, and it also may abandon the leaf prematurely.

The combination of the lack of response to kairomones and the hindrances caused by heavy whitefly attack result in a moderately or lightly infested leaf having a better chance of being completely parasitised than a heavily infested leaf. Predators, on the other hand, thrive best on heavily infested leaves. Their juvenile stages cannot fly to another leaf in search for food, and so it is advantageous for the predator to oviposit on a leaf with an abundance of whitefly immatures. Thus parasitoids and predators complement each other for different host population levels.

Inundative releases: *Encarsia formosa* which is successfully used in greenhouses to control whitefly, especially the greenhouse whitefly *Trialeurodes vaporariorum*, is also being tried out against *Bemisia*. The parasitoids are released at the rate of four parasitoids per host, three to four times at 10-day intervals. A problem often arises in the control of a mixed population, since *E. formosa* prefers to attack the greenhouse whitefly and may ignore *B. tabaci* in the presence of the former. This method of control may work well in greenhouses but is not recommended in field conditions, where dispersal is so much greater. Furthermore, the number of necessary parasitoids to be released at even the same density as in the greenhouse, would be economically prohibitive for a field crop that is usually grown less intensively and on a larger scale than a greenhouse crop. Therefore, the idea is not to obtain control through eradication, but through classical methods (i.e., the release of natural enemies that will become established in the field and reduce the pest populations). If this does not work, we have to find other ways such as the use of selective insecticides.

[Note: The developing *Encarsia formosa* within greenhouse whitefly nymphs causes the whitefly puparium to become black. This distinctive feature does not develop when *E. formosa* develops on *B. tabaci*. Black puparia may form also in other species of parasitoids and whitefly, yet they usually can be distinguished from those formed by *E. formosa*.]

G. Monitoring

Yellow traps: this is a simple flat board that is bright yellow. Various sticky materials such as Tanglefoot or Stickum are used to trap the whitefly. If it is to be used only for a short time, say, a few hours, oil of almost any type can also be used. Monitoring *B. tabaci* is difficult. Many adults are caught but there is often no good correlation between what is caught and what exists on the leaves. The sex ratio of the catch may vary from 70 per cent male to 70 per cent female. It is important to bear in mind that whiteflies tend to land on the lowest spot relative to the ground, so that the trap should be placed close to the ground. The trap should be horizontal, because if it is placed vertically only a small percentage of the horizontal orientation may be caught. If the trap is placed the previous evening or in the early morning a good measure of events will be obtained by 11.00 am since most flight occurs before that time. The measure obtained is obviously influenced by the proximity of plants. If a trap is placed in a fallow field you may not catch as many. Always place the trap so that it is exposed to the sunlight, as up to 10 times more will be caught in the sunlight than in the shade. Decisions should be made at a local level on exactly what height and size of trap to use. It is possible that placing the trap off the ground is easier and will still catch adequate *B. tabaci* for your monitoring purposes.

Another monitoring device is to use a sticky pan placed next to a plant and shake the plant onto it during a certain interval (e.g., a few seconds). This is a practical method which may be found useful, and may even give a better idea of what is actually on the plant than the stationary trap. The horizontal trap will pick up adults moving into or off the crop, but ina stationary situation, in which *B. tabaci* are already on the plant, a horizontal trap placed between the crop rows may not be very effective in monitoring them. Farmers in particular try to estimate the levels of the pest for the purpose of deciding when to treat by simply passing through the crop and assessing how many adults fly up as a result of the disturbance. However, this is not recommended. Some people have also found yellow traps good monitoring devices for parasitoid adults. In Israel, however, we have not found this useful for monitoring parasitoids.

Counting of immatures on the leaf is a reliable but tedious method. Whiteflies should be 3rd instars and up; 1st and 2nd instars are really too small and too numerous to count correctly. Counts can be done on whole leaves or part of the leaf. Numbers can be assessed at different levels or parts of the plant, depending on the plant species and crop. There is a large body of literature on sampling that should be consulted for details.

In addition, whilst counting immatures, parasitism can also be monitored. This can provide very useful data because if high levels of parasitisation are found, one may want to avoid spraying. However, a word of caution - we have found that once the whitefly has emerged, the empty puparium of the whitefly whether parasitised or not, may not remain on the leaf for a predictable amount of time. Therefore, it is only possible to estimate parasitism by counting full, living late larvae or pupae, before arriving at counting the leaf.

H. Control

Since *B. tabaci* transmits viral diseases, preventing damage by this pest will often mean changing cultural practices; e.g. in Florida and the Dominican Republic large scale sanitation procedures are now undertaken for tomatoes. These include coordinating uniform planting times, treatments and harvesting over the largest possible area, so that a minimal transfer of viruses from mature to young plants will occur. This approach includes a period during which the field is left fallow without either crops or weeds in order to reduce the possibility of the virus being carried over to the next tomato crop.

Due to the resistance that *B. tabaci* has built up, many insecticides have proven to be ineffective against whitefly. Thus, it is very important to consider ways to conserve those materials that can still be used so that they will continue to be useful in the future. Moreover, it is important to coordinate the correct use of insecticide over wide areas because if resistance starts in one small region it will rapidly spread with the movement of the whiteflies.

Mulching

Whiteflies are strongly attracted to the colour yellow. In a 1927 publication of work done in Palestine it was mentioned that when the ground between plants was covered with straw, the whiteflies did not affect the tomatoes that would otherwise have been heavily infested. The reason was that the whiteflies preferred to land on the straw due to its yellow colour. The straw heated up from direct sun rays and its temperature reached some 50° to 60°C. Once the whitefly had landed they were overcome by the heat and could not manage to fly off again and were killed. This worked as long as the straw was exposed and yellow, and was not shaded by the growing plants. Nowadays, we may use yellow or aluminium coloured plastic mulch or fabric which is very effective as long as it receives direct sunlight. In Florida, yellow, white and aluminium mulches were tested and found to be equally effective, delaying subsequent insecticide treatments by 10-20 days. Although it is not a complete solution, the delay in treatment is important in itself since it will also delay the build-up of resistance.

Screening

Plants can be protected by a nylon screen or mesh which stops the whitefly from reaching them. The mesh must be about 0.5 mm. It is not possible to screen off a whole field but the idea is to protect seedlings grown in a small area which are subsequently moved to the field. For example, tomatoes can be kept under screening for the first six weeks after sowing. In this way, the plant has a whitefly- and virus-free period to establish itself and in many cases, even though whitefly then attack, the plant will have already set some fruits before it has been attacked by viruses, and only a moderate degree of additional protection (e.g., through insecticides) is necessary in order to obtain a satisfactory crop. Such a crop would not have been attainable without the early protection of the plants.

Natural enemies

Although natural biological control is important, it is often too slow in the case of *B. tabaci* to be of use to farmers, who want immediate action. It is very difficult to expect them to wait and see their crops being attacked in the hope that natural control will eventu ally bring the pest under control.

In the case of the Caribbean, if we look hard enough, many natural enemies will undoubtedly be found. They may be able to assist in controlling *B. tabaci* but it is not realistic to expect them to control the problem over the short term. A solution must be found for the immediate short term whilst at the same time allowing the long-term effect to take place. To help this process we can use:

1. **Refuge plants,** such as ornamentals or shrubs. If we do not mind certain plants being attacked by *B. tabaci*, they can be a useful refuge for natural enemies to build up on.
2. **Resistant/tolerant crops:** there is no edible vegetable crop or variety which is totally resistant to *B. tabaci*. There will always be some attack, but by using tolerant or resistant varieties it is possible to reduce populations to levels where other control measures (e.g. biological control) can more readily bring about adequate control. For example, in Israel a resistant tomato variety has been developed against Gemini virus. Additional varieties exist, which

exhibit some tolerance to virus infection, so if these are used in conjunction with other methods (e.g. mulching, screening) a good crop can be obtained.

3. **Banker plants:** Lance Osborne (Florida) reports that papaya can be used as a banker plant because it the only host of the papaya whitefly. He placed a large number of predators on papaya trees within a greenhouse with ornamentals that he wanted to protect; after a short time the predators reduced the whitefly populations and then moved over to the adjacent ornamentals where they started to feed on *B. tabaci.*

   It is quite possible that parasitoids of the genus *Encarsia* could also be used in the same way because they, like predators, have a wide host range. Such a technique might be especially suitable for the tropics where a large number of whitefly species and natural enemies exist, and many of these are not species-specific.

4. **Selective insecticides:** detergents - it has been known for many years that soap will kill insects on plants. However, the soap can also kill the plant. A detergent has been developed which is completely biodegradable and will not harm the plant. It serves as an immediate form of control and has no residual action; i.e., it exerts no protective effect, but it is a useful way to reduce the whitefly population drastically. The soap will kill adult parasitoids but those developing parasitoids inside their hosts will tend to survive.

Insect growth regulators (IGRs) - e.g., buprofezin (Applaud) or pyriproxyfen (Tiger): the main effect of these substances is on egg hatch and instars 1 & 2 of the whitefly nymphs. They hardly affect instars 3 and 4 of the whitefly. Interestingly, parasitoids (except for *Amitus* species) only rarely affect instars 1 and 2, and mainly attack and develop in instar 3 and 4. In theory, therefore, IGRs will kill instars 1 and 2, but not the parasitoids nor the adult whitefly. One should thus obtain a drastic reduction of the next generation of whitefly but with little effect on the parasitoid population. IGRs are relatively persistent so eggs laid by whitefly after treatment should suffer a high mortality. Those eggs that are laid on unsprayed vegetation will develop, but may later be attacked by parasitoids when they reach the 3rd instar.

So far we have little knowledge of the effect of IGRs on predators, but there is some indication that they may affect them adversely.

Timing and dose rates are, of course, important, but when used judiciously with other control techniques IGRs can work to kill whitefly and yet be favourably integrated with the activity of natural enemies. However, caution must be exercised not to overuse any material, since the chances of resistance build-up are directly proportional to the frequency of exposure to the material. Therefore, materials like IGRs should be used once each season, while the encouraged natural enemies and other methods should do the rest.

Integrated control

As already stated, no one method can bring about satisfactory *B. tabaci* control for all crops and crop conditions. Consequently, it is important to learn to recognise the particular conditions under which a crop is grown and then to formulate the best combination of control measures available. In all cases, it is most advisable to encourage natural enemies, since they are the only permanent solution against which no resistance builds up, which do not pollute the environment and are not hazardous to use.

In this connection, it should be emphasised that virus infections are a function of the number of vectors in the environment. Thus, it is very important to reduce overall populations in order to reduce the amount of potential virus inoculum in the environment. Natural enemies on non-crop plants are very important in this regard, because they are the only agents that are permanently present controlling these populations.