# Conclusions

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The Tropical Whitefly Integrated Pest Management (TWF-IPM) Project is one of the most ambitious projects ever undertaken in the IPM area. The magnitude of the project responds to the global distribution of the pest and the severe damage caused by whiteflies to major food and industrial crops in tropical and subtropical agricultural regions of the world (Jones, 2003). The emergence of a more prolific and polyphagous biotype (B) of *Bemisia tabaci* (Gennadius) has further complicated the control of this pest on alfalfa (*Medicago sativa* [L.] subsp. *sativa*), cotton (*Gossypium hirsutum* L.), common bean (*Phaseolus vulgaris* L.), tomato (*Lycopersicon esculentum* Mill.), soybean (*Glycine max* [L.] Merr.), lettuce (*Lactuca sativa* L. var. *capitata* L.), peas (*Pisum sativum* L.), broccoli (*Brassica oleracea* L. var. *italica* Plenck), collard (*Brassica oleracea* L. var. *viridis* L.), cabbage (*Brassica oleracea* L.) and okra (*Abelmoschus esculentus* [L.] Moench) (Gruenhagen et al., 1993; Godfrey et al., 1995; Morales and Anderson, 2001). In developing countries of Latin America, sub-Saharan Africa, India and south-east Asia, *B. tabaci* is an efficient vector of plant viruses affecting important food crops, particularly common bean (Morales and Anderson, 2001), cassava (*Manihot esculenta* Crantz) (Fargette et al., 1990; Gibson et al., 1996), tomato (Polston and Anderson, 1997) and peppers (*Capsicum* spp. L.) (Morales and Anderson, 2001). In subtropical and mountainous regions, the whitefly species *Trialeurodes vaporariorum* (Westwood) attacks crops such as potato (*Solanum tuberosum* L.), tomato, common bean, several cucurbits and different vegetables (Boiteau and Singh, 1988; Cardona, 1995). Until recently, cultivated grasses (Gramineae) were among the few plant species spared by whitefly pests. Within the last decade, devastating whitefly attacks have taken place in important food and industrial crops such as rice (*Oryza sativa* L.), sorghum (*Sorghum bicolor* [L.] Moench), sugarcane (*Saccharum officinarum* L.) and pastures (author's observation). Not surprisingly, whiteflies were considered by popular news media (e.g., CNN and Newsweek) as the "pest of the 20th century" and their importance as a major agricultural pest remains high in the new millennium.

Whiteflies harm plants in different ways by extracting sap, covering plants with a sticky sugary substance (honeydew) that affects the quality (e.g., sticky cotton) or promotes the growth of fungi (sooty mould) on plant surfaces blocking photosynthesis (Henneberry et al., 1996) and by transmitting viruses (Markham et al., 1994; Jones, 2003). In heavily infested plants, hundreds of immature and adult

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whiteflies can be found feeding on a single leaf, resulting in rapid plant death from the massive loss of nutrients. Sooty mould can also provoke plant death. And, finally, whitefly-transmitted viruses are among the most damaging viral pathogens known, often causing total yield losses. Genetic immunity to these viruses is rare in most of the plant species attacked by begomoviruses.

Although whiteflies have been associated with agriculture for centuries, these insects were only recognized as pests in the 1950s (Ernst, 1994), coinciding with the development and intensive use of agricultural pesticides following World War II. Half a century later, most farmers are still not aware of the taxonomic or biological differences that characterize different species and their physiological variants (biotypes). Nor are they informed about the role of these species as pests and/or vectors of plant viruses. Therefore, farmers apply insecticides whenever they see whiteflies on their crops. In rare instances, farmers who have received some technical assistance apply insecticides when the population of the pests has reached a pre-determined level, known as the “damage threshold”. Whereas these “target” or “threshold” applications may be effective in controlling whiteflies as pests (Chu et al., 1995; Riley and Palumbo, 1995), they are totally ineffective in the case of whitefly-transmitted viruses. Basically, few adult individuals of a whitefly vector can transmit a virus long before its population is noticed in the field or reaches a particular density on susceptible plants.

The introduction of the “B biotype” of *Bemisia tabaci* in the Americas (Brown and Bird, 1995) has drastically increased the capacity of this whitefly species to cause damage to a larger number of different cultivated plant species and adapt to new environments. Farmers that try to escape *B. tabaci* in the tropical lowlands and mid-altitude (500-900 m) regions by growing their crops at higher altitudes are often disappointed to find yet another whitefly pest, *Trialeurodes vaporariorum*, in the highlands. Unlike *B. tabaci*, the main whitefly pest and vector of plant viruses in the tropics, *T. vaporariorum* was considered a mere nuisance in crops grown under controlled conditions (e.g., glasshouse, screen-house conditions). Currently, *T. vaporariorum* is also a major pest of field crops in the highlands and temperate regions of the world and the number of plant viruses transmitted by this species is steadily growing (Jones, 2003).

Pesticide abuse is a common factor in the case of the main whitefly pests, regardless of the crops and ecosystems affected. The excessive application of insecticides, often using inadequate chemicals, alters the delicate balance between insect pests and their biological control agents (i.e., predators, parasitoids and entomopathogens). In the absence of natural enemies, whitefly populations increase freely on susceptible crops and eventually develop resistance to the most frequently used insecticides (Omer et al., 1993; Dennehy and Antilla, 1996). Modern agricultural practices, such as the intensive cropping of diverse plant species that act either as suitable feeding or reproductive hosts, further contribute to the exponential increase of whitefly pests in disturbed environments (Godfrey et al., 1995). Last but not least, climate change has played a major role in the increasing outbreaks of whitefly pests throughout the world. As more forest and wild lands are cleared for agricultural purposes, the climate becomes drier and warmer, conditions that shorten the life cycle of whitefly pests and thus increase their populations (Chu et al., 1995).

Small-scale farmers are trying to grow more profitable crops in order to maximize the output of their limited landholdings. In the absence of proper technical assistance, farmers face several problems: first, they are not familiar with new crops, let alone with their phytosanitary problems. Exotic crops can and will encounter different pests in their new environments. Often, exotic pathogens and pests are introduced with imported plant germplasm. In the case of horticultural crops, and particularly vegetables, the new cultivars have been bred in temperate countries, even though the origin of some of these plant species is the tropics (e.g., tomato and peppers). This means that new crops may not be well adapted to tropical conditions, including their lack of resistance to local pests. Although technical assistance to small- and medium-scale farmers is not forthcoming, pesticide salesmen manage to reach every corner of the rural world. This explains the reliance of farmers on pesticides to protect their crops.

The main problem of most IPM practices is their failure to control pests before they cause economic damage. IPM is often wrongly associated with "organic agriculture", in which chemical insecticides do not have a place. Unfortunately, once an agricultural region has been significantly modified by the introduction of new crops, and its biological equilibrium broken by the intensive use of pesticides, whitefly populations are usually too large to be controlled by non-chemical IPM practices, such as biological control agents or yellow traps. Thus, the TWF-IPM Project has been following a different approach based on the rationalization of chemical control, using the most effective yet specific and safe systemic insecticides at the proper time. This strategy rapidly reduces the number of insecticide applications to a minimum, allowing the recovery of the beneficial fauna over time. Once this condition is met, other IPM strategies can be incorporated, such as cultural practices, use of entomopathogens, physical barriers and legal measures, among others. A significant reduction in the use of pesticides also contributes to lower production costs and higher profits for farmers, which will become critical factors for emerging economies in the age of free trade agreements. Last but not least, men, women and children in developing countries are inadvertently consuming vegetables contaminated with highly toxic pesticides. The medium- and long-term effects of these toxic residues are difficult to determine, but they may range from chronic illness to life-threatening ailments, including cancer. Reducing pesticide use in vegetable crops to safe levels should greatly contribute to vegetables free of toxic pesticide residues, and improved health standards in rural and urban populations in developing countries.

The history of cassava mosaic disease (CMD) is over a century old (Fauquet and Fargette, 1990) and it has been almost half a century since whiteflies emerged as pests and vectors of plant viruses of economic importance. New viruses have been appearing throughout the tropics and subtropical regions of the world with a high frequency (Polston and Anderson, 1997). With the advent of molecular techniques, the list of whitefly-borne viruses has increased exponentially in the last 3 decades. Altogether, considerable research has been conducted on these pests, and yet, their impact seems to increase every year in developing countries. We have already discussed some of the factors that have contributed to the unexpected dissemination of whiteflies and whitefly-borne viruses. Undoubtedly, the advent of chemical insecticides and their intensive use in crops, such as cotton, elevated whiteflies to the category of pests. Another important epidemiological factor, the diversification of crops in developing countries, both as export commodities and cash crops, has also played a major role in the increase of these pests.

The importance of some of the new crops lies in their role as reproductive hosts to whiteflies (Tsai et al., 1996). These crops need not support very large populations of whiteflies, but rather occupy large areas or regions. The best example is perhaps soybean, which was rediscovered in Latin America in the 1970s as a potential export crop, increasing the total area planted to over 10 million hectares. Because individual soybean plants do not support large populations of whiteflies, primarily *B. tabaci*, soybean growers do not control this insect in the soybean crop. When the soybean crops mature at the end of the year, common beans are planted, provoking the migration of whiteflies from the soybean fields to the young common bean plantings. The search for more profitable crops has led small- and medium-scale farmers to diversify and intensify their cropping systems, providing an opportunity for whiteflies to dispose of different food sources throughout the year.

Crop improvement has played an important role in both the onset and control of whitefly-related problems. In the case of cassava, the lack of CMD-resistant cultivars and/or the limited adoption of mosaic-resistant germplasm has perpetuated the cultivation of CMD-susceptible cassava clones (Morales, 2001). Consequently, the causal viruses find hosts that act as virus reservoirs and permanent sources of inoculum for the whitefly vector. In sub-Saharan Africa, this situation has made possible the occurrence of multiple infections and subsequent recombination of different CMD-inducing virus species (Pita et al., 2001). The recombinant whitefly-transmitted begomovirus has caused severe yield losses in Uganda and some neighbouring countries, necessitating the implementation of a famine relief project. In the case of common bean, the downsizing of the national and international programs that worked on the development of begomovirus-resistant bean germplasm in Latin America has resulted in the abandonment of prime agricultural regions where common beans used to be produced. This happened because of the emergence of more pathogenic begomoviruses and the breakdown of the resistance available in the earlier generations of improved common bean cultivars (Morales, 2001).

The economic crisis that affects most national agricultural research programs in developing nations has greatly affected the flow of technical information to farmers and, consequently, their capacity to manage complex and severe crop production constraints such as the whitefly problem. Industrialized nations are currently controlling whiteflies with a new generation of systemic insecticides that are more efficient and selective (Chao et al., 1997). They are available in developing countries, but their price is very high for most small-scale farmers, who continue to use ineffective and highly toxic contact insecticides, often on a daily basis. These contact insecticides have practically annihilated the beneficial fauna and induced resistance in whitefly pests, giving rise to very large populations of whiteflies that can overcome most control methods, including systemic insecticides. Fortunately, some of the new systemic insecticides are being produced as “generic” compounds in developing countries, at lower prices. These problems have forced many farmers to abandon the cultivation of susceptible crops in prime agricultural regions.

The TWF-IPM Project has gathered enough evidence to suggest that the whitefly problem can be managed with the collaboration of farmers, by providing proper and timely technical assistance. The challenge for the project is to find the most appropriate communication means to disseminate the IPM technology that has been found to be effective and economically viable for small-scale farmers. To this end, the TWF-IPM Project is about to initiate its third and final phase to disseminate and scale out suitable IPM technology using farmer participatory research and different communication channels to reach affected farmers throughout the tropics, wherever whiteflies are a food production constraint. We are confident that well-informed farmers will be able to reduce the number of application of insecticides, lower production costs, increase profits, and reduce environmental contamination and human health hazards. Ultimately, farmers will be able to recover the biological equilibrium of their agricultural ecosystems, and thus prevent future whitefly outbreaks.

The information presented in this book represents a major achievement in terms of compiling the international and national (grey) literature and knowledge available on the extent and socio-economic importance of whiteflies as pests and vectors of plant viruses. This information has been essential in selecting the most promising and viable IPM strategies to be tested in Phase II of the TWF-IPM Project. The information contained in this book also reflects the interest and hard work of many colleagues who now form one of the most extensive research networks in the tropics. This joint effort has already yielded visible results in terms of raising awareness about the nature of the whitefly problem, particularly in relation to the key issue of pesticide abuse, and the use of appropriate methods to characterize whitefly pests and diagnose whitefly-borne viruses. The design, validation, implementation and success of IPM methods recommended to control whiteflies and whitefly-transmitted viruses largely depends upon a solid knowledge base.

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