The Systemwide Tropical Whitefly IPM Program

Activity 1. Coordination.

Executive Summary

Background: The Co-ordinator's position was created by the original Task Force that conceived the Tropical Whitefly IPM Project (TWFP), to co-ordinate the various research activities conducted by the different subprojects that operate in Africa, Asia and Latin America. The TWFP was born under the umbrella of the CG System-wide IPM Programme, but Phase I was initiated thanks to the financial support of the Danish Development Agency (DANIDA) following negotiations with the Co-ordinator of the TWFP.

During Phase I, the appointed Co-ordinator followed an active global agenda to incorporate more research groups and additional donors to pursue complementary research activities, such as the search of sources of resistance against whiteflies in cassava (New Zealand AID) and against whitefly-borne viruses of horticultural crops in Asia (ACIAR).

The TWF Coordination (CIAT-based) has maintained the communication and coherence of the research conducted by the different subprojects of the TWFP in: Africa (two cassava subprojects, one of which is also financed by USAID); Asia (begomoviruses of horticultural crops, financed by ACIAR); Central America, Mexico and the Caribbean (common bean and horticultural crops in Mesoamerica); the Andean Region (common snap beans); and East Africa (horticultural crops and begomoviruses). The coordination of the TWFP has also maintained close linkages with other DFID-funded whitefly projects managed through the Crop Protection Programme (CPP), particularly in Africa and Asia, and has facilitated the interaction and exchange of sources of resistance between IITA and CIAT (cassava) and between national programs (CENTA-El Salvador and INIFAP-Mexico and AVRDC).

The Coordinator of the TWFP created and supervises the Communications Office located at CIAT, which manages the databases that contain global information on pertinent literature, whitefly research networks, collaborating scientists and technical guidelines, mainly through a Web Page created for this purpose. This office also compiles and submits technical reports produced by the various subprojects of the TWFP.

Project purpose: The DFID-funded Tropical Whitefly IPM Project (TWFP-Phase II) sought to implement sustainable pest management strategies to control the devastating yield losses caused by whiteflies and whitefly-transmitted viruses in cassava, sweet potato, common bean, tomato, sweet pepper, chilli, and other horticultural crops, and, thus, prevent hunger and famine, and ultimately improve the livelihood of resource-poor farmers in developing countries of Africa, S.E. Asia, and Latin America.

The specific objectives of Phase II of the TWFP were to : 1) Strengthen the pan-tropical whitefly research network created during Phase I by developing information management and exchange channels to disseminate research findings among project collaborators (NARIs, Universities, NGOs, Advanced Research Laboratories, Farmer Associations, Policy Institutions, and the general public interested in these topics). 2) Undertake basic studies on whitefly population dynamics and disease epidemiology in order to understand whitefly/virus pathosystems and thus implement effective IPM strategies. 3) Select and evaluate the most promising IPM measures available to date in selected 'hot spots' identified in Phase I, in order to develop area-wide IPM packages for crops and/or cropping systems currently affected by whiteflies and whitefly/transmitted viruses. 4) Develop training materials for the last phase (III) of scaling up the dissemination of results on the most suitable IPM packages validated in the different whitefly-affected regions of Africa, Asia and Latin America.

The economic importance of whiteflies as pests and vectors of plant viruses was recognised in the late 1980s, not only by developing countries but by industrialised nations as well, including the United States, where a "National Research, Action, and Technology Transfer Plan" was conceived in 1991 to combat the 'silverleaf whitefly' (*Bemisia tabaci* biotype B), and European and Middle East countries in the Mediterranean region. Popular news media called it the 'Pest of the Century' and yield losses have been calculated in the billion of dollars, leading in some countries to famine, as in the case of Uganda, following the emergence of a recombinant variant of different viruses associated with African cassava mosaic disease. Whitefly-transmitted viruses also caused the collapse of food and industrial crops in Latin America, particularly in Central America, Mexico and the Caribbean region. Nascent industries (tomato paste) in the Dominican Republic and Haiti had to close down following the epidemics of *Tomato yellow leaf curl virus* in the 1990s. The entire industry of vegetable production for export to North America also collapsed in the 1990s due to the emergence of numerous viruses transmitted by *B. tabaci* throughout Mesoamerica.

Small-scale farmers throughout the tropics have been struggling for the last two decades to increase the income derived from their limited land resources, by diversifying their subsistence crops with more valuable crops, mainly vegetables. Unfortunately, neither national nor international agricultural research institutes have provided technical assistance to resource-poor farmers for non-traditional crops, leaving poor farmers in the hands of pesticide salesmen. As a result, production costs have increased (up to 60% of current vegetable production costs are related to crop protection), environmental and human contamination due to pesticide residues has become a serious problem, agricultural produce is rejected by international markets that test for pesticide residues, and pest problems have worsened due to the development of insecticide resistance and elimination of the beneficial bio-control fauna. The TWFP focuses on all of these production and environmental problems with the ultimate purpose of improving the livelihood of the poor rural and urban population of developing countries in the Tropics.

Coordination activities: The Coordination of the TWFP has contributed to the strengthening of whitefly management networks in developing countries, and to the exchange of information compiled from all of the accessible and grey literature sources on whiteflies. A database has been created at CIAT, which has also establish links with a complementary database created by USDA on whitefly research conducted primarily in the U.S.A. and other developed countries. A directory of professionals conducting research on whitefly-related production problems around the world has also been created.

A Web Page (www.tropicalwhiteflyipmproject.cgiar.org) has been gradually developed to make all of the available information on whitefly and geminivirus management, accessible to users around the world.

The project has a Communication Office and a communications specialist in charge of information dissemination and data management, including Geographic Information Systems (GIS) to implement more interactive channels for data reporting and sharing among users. The Co-ordinator has been involved in the improvement of the information dissemination capabilities of the TWFP, including various articles, presentations and publications that describe the work and results obtained by the TWFP and related CPP projects financed by DFID.

The main publication in the pipeline is a book containing the results of all of the diagnostic work conducted in Phase I: surveys, biological characterisation of whitefly species/biotypes, molecular characterisation of begomoviruses, description of crops affected, identification of 'hot spots' in east and west Africa, the Andean region, Central America, Mexico and the Caribbean, and socio-economic studies.

The building of the Tropical Whitefly Research Network started in Phase I, and it is now linked to all the national and international projects that conduct research on whitefly pests and related problems around the world. This network includes the International Whitefly Studies Network, managed from the U.K., which includes all of the European countries that suffer crop losses caused by whiteflies and the different viruses these insects transmit, mainly in the Mediterranean region.

The TWFP Coordinator is also involved in the strengthening of National Agricultural Research Institutions (NARIs) that have not been previously covered by the TWFP, but which have asked the TWFP for assistance to manage severe whitefly problems. This has been the case of the Andean Region, where whiteflies have recently emerged as direct pests and virus vectors, particularly in Bolivia, Perú and Colombia. The Coordinator has been invited by these Governments to observe the whitefly problems that affect crops, such as potato, common bean, tomato, and cucurbits. A special report was prepared on the whitefly problem of mixed cropping systems in the mesothermic valleys of Bolivia, where DFID has special projects. With respect to collaborating NARIs, the TWFP Co-ordination has provided training for some national program scientists, particularly in the area of molecular characterisation of plant viruses and whitefly species/biotypes, but also in the area of rural development and participatory research.

The emergence of *Bemisia tabaci* biotype B, as a vector of viruses affecting common bean and tomato in the main agricultural region of Colombia, the Cauca Valley, is primarily a consequence of unusual climatic phenomena (climate change), represented by persistent, dry conditions for two consecutive years beginning in 2001. The attacks have been so severe that snap bean production has been eradicated from the valley in the last year. The TWFP Co-ordinator organised a series of talks for tomato farmers in order to explain the nature of the problem and recommend and IPM package, which has been successful in maintaining tomato production in this region.

In 2003, the Co-ordinator received an urgent request from El Salvador to diagnose an unusual whitefly outbreak in cereals and grasses, mainly rice, sorghum, maize, and forage pastures. This is the first time that grasses have been attacked in Mesoamerica by whiteflies. Samples were sent to CIAT where the TWFP's taxonomist, Ms. María del Pilar Hernández, identified the exotic whitefly pest as *Aleurocybotus occiduus*. This is apparently a neotropical whitefly species that has been previously reported in S.W. USA, and the Amazon region of Perú, where it was also reported on rice. The Coordinator visited the affected rice-growing area in N.W. El Salvador and confirmed the complete destruction of over 35 has of rice **(Figures 1 and 2)** and several sorghum fields.

Figure 1. Total yield loss in rice fields of El Salvador caused by the emergence of a new whitefly pest capable of attacking cereals.

Figure 2. Damage and pupae of the new whitefly pest of rice in El Salvador.

The TWFP has also provided information and advice to CPP ("Adaptive evolution within *Bemisia tabaci* and associated *Begomoviruses*: A strategic modelling approach to minimising threats to sustainable production systems in developing countries" by Frank van den Bosch and M.J. Jeger), and other international projects currently engaged in the validation of sustainable IPM practices and modelling of whitefly/geminivirus epidemics.

The Coordination of the TWFP has also facilitated six meetings of sub-project coordinators to discuss project activities and future research strategies. The last two meetings to plan Phase III took place at CABI, U.K., and CIMMYT, Mexico, with the participation of NRInternational (CABI meeting), all sub-project coordinators, and other potential participants in Phase III. Several concept notes have been prepared in anticipation of Phase III.

Outputs

In terms of Information Management and Technology, the TWFP has made a significant effort to collect all the pertinent available and 'grey' literature on whiteflies and whitefly-borne viruses published around the world. To complement this effort, the TWFP has also linked with the extensive bibliography of *Bemisia tabaci* compiled from various sources since 1995 by USDA scientists in Arizona. These extensive databases and hard copies of the original documents are still in the process of transformation into electronic documents, but can be consulted for the most part by contacting the TWFP's Information Officer at CIAT, Palmira, Colombia.

Two publications were produced to: 1) promote the integration of the TWFP and the CPP projects conducting research on whitefly pests and whitefly-transmitted viruses. This publication, "A United Effort Against a Global Pest", has been distributed in Latin America, Africa, Asia and Europe. A second publication describing the various sub-projects that integrate the Tropical Whitefly Project, its participating institutions and donor agencies, was recently published for global distribution. The Coordination of the TWFP has also facilitated six meetings of sub-project coordinators to discuss project activities and future research strategies. The last two meetings to plan Phase III took place at CABI, U.K., and CIMMYT, Mexico, with the participation of NRInternational (CABI meeting), all sub-project coordinators, and other potential participants in Phase II.

The TWFP Coordination also promoted the dissemination of information regarding information on IPM strategies and packages that have been shown to be effective for the management of whitefly pests and whitefly-transmitted viruses in Latin America. Three electronic documents on: 1) management of whiteflies as direct pests in highland crops; 2) management of whiteflies as virus vectors in mixed cropping systems in the tropics; and 3) use of physical barriers for the control of whitefly-borne viruses in horticultural crops in the tropics, have been made available through the TWFP Web Page. The TWFP has also provided information and advice to CPP ("Adaptive evolution within *Bemisia tabaci* and associated *Begomoviruses*: A strategic modelling approach to minimising threats to sustainable production systems in developing countries" by Frank van den Bosch and M.J. Jeger), and other international projects currently engaged in the validation of sustainable IPM practices and modeling of whitefly/geminivirus epidemics.

The Coordination has maintained permanent contact with all the national and international institutions involved in Phase I and new partners in preparation for Phase III: technology dissemination through farmer participatory research. The Coordination has also maintained the communication with all project partners and the donor community, since the termination of Phase II on March 31st, 2004, to assure the continuity of the project. A series of Concept Notes have been prepared to this end.

Contributions of Outputs to Developmental Impact

Poverty alleviation: This project primarily responds to the needs of resource-poor farmers in need of technical assistance to manage whitefly pests and whitefly-transmitted viruses in staple and cash crops. In the case of basic food crops, such as cassava in Africa and common bean in Latin America, whitefly management is necessary to prevent significant and even total yield losses induced by African cassava mosaic and bean golden/yellow mosaic viruses. The deployment of virus-resistant cassava and common bean cultivars in Africa and Latin America, respectively, assures the food and the regular income derived from these crops by poor farmers. The TWFP has also provided technical assistance for small-scale farmers on IPM measures designed to protect high-value vegetable crops in mixed cropping systems. Vegetable crops, such as tomato, pepper and chillies, provide resource-poor farmers with additional income in very small areas (e.g. a tenth of a hectare planted to tomato, may produce more income than 4 has of common bean or maize). Vegetable production is not possible in whitefly-stricken agricultural areas without the adoption of effective IPM practices.

Food security: The TWFP has intervened in the mitigation of a famine caused by the emergence of a new recombinant whitefly-transmitted virus of cassava in East Africa (USAID funds). This event demonstrates that whiteflies can cause food security problems. In Latin America, the damage caused by whitefly-borne viruses in common bean plantings, caused the abandonment of over a million hectares to bean production. The resulting shortage forced many Latin American countries (including Brazil, the main producer of common bean in the world) to import beans from countries as far as China. Central America, Mexico and countries in the Caribbean region have to import beans on a regular basis, because of the whitefly problem. Vegetables have become an important component of the diet in developing countries, where the cost of sources of animal protein is beyond the purchasing power of poor people.

Generation of income: Horticultural crops have become an important source of income for small-scale farmers in developing countries of Asia, Africa and the Americas. A hectare of tomato, produced under high whitefly/virus pressure thanks to the IPM measures implemented by the TWFP in Mesoamerica, may produce over £ 5,000 in income (as compared to a £ 100 profit obtained from a hectare of maize or common bean). Hence the emphasis of the TWFP on mixed cropping systems for food security and income generation, particularly in East Africa and Latin America. The co-ordinator of the TWFP has secured the help of AVRDC's breeders in Taiwan, to initiate genetic improvement activities for tomato and peppers in Latin America, the centre of origin of these crops.

Sustainable use of Natural Resources: The implementation of IPM measures, such as use of virus- or vector-resistant varieties, use of physical barriers, and bio-control agents, results in a major reduction of pesticide applications. This fact has been demonstrated in the experimental trials conducted in Mesoamerica and the Andean region. The DFID-funded CPP and TWF projects are unique in combining food production with natural resource management (NRM) practices. Emphasis on NRM per se, without a food production component, has led to unimaginable levels of pesticide abuse in developing countries, in detriment of the environment (contamination of soils, water sources and the environment), public health (applicators, rural communities, and consumers of highly contaminated produce), and the beneficial fauna (bio-control organisms).

As mentioned before, the co-ordinator of the TWFP has promoted three different meetings to discuss with subproject co-ordinators, the best approach to promote the findings of the work conducted so far by the project. In general terms, the TWFP recognises the need to scale up the implementation of IPM measures found to be effective and sustainable to control whitefly pests and the viruses that these vectors transmit. To this end, the Co-ordinator has contacted the Farmer Participatory Research (FPR) and Impact Assessment Groups of the System-wide IPM Programme, to develop a joint work plan for Phase III. This objective does not preclude the need to continue some basic research activities in the area of pathogen and pest monitoring, ecology and epidemiology of whiteflies and whitefly-borne viruses, and refinement of IPM strategies. The organisation of Farmer Field Schools (FFS) and analysis of policy issues related to this project, are also contemplated.

Further studies are necessary to link small-scale farmers to markets, and to develop agro-enterprises. Area wide impact assessment studies are also needed to determine the real contribution of the TWFP to poverty alleviation in target countries. To fulfil these objectives, the TWFP has been contacting Information and Communication specialists on electronic, radio and written media to chose the most effective channels to deliver the technology generated.

One of the major obstacles to the dissemination of technology in its initial stages ('pilot sites') has been the lack of trained personnel in FPR and FFS. There is a need for qualified personnel knowledgeable in transferring IPM technology to small-scale farmers, emphasising the economic benefits of adopting IPM measures. The co-ordination and subproject leaders of the TWFP have taken initial steps to establish collaborative links with FPR specialists working in the target regions, particularly in Africa and the Andean region. In Central America, the co-ordinator and leader of the Mesoamerican subproject has made possible the training of a national program scientist in Rural Development and Farmer Participatory Research at a regional international centre (CATIE).

DFID has expressed its interest in continuing its support to the TWFP in order to disseminate the technology generated by the different subprojects in sub-Saharan Africa, South East Asia, Mesoamerica and the Andean region.

Activity 2. Technical Report: Mesoamerica.

This output is from a research project funded by the United Kingdom Department for International Development for the benefit of developing countries. The view expressed are not necessary those of DFID.

Executive Summary

Mesoamerica is the region most severely affected by whiteflies and whitefly-transmitted viruses in the world. The Mesoamerican subproject of the Tropical Whitefly IPM Project (TWFP) was conceived to help small-scale farmers manage whitefly-borne diseases in basic food and high-value horticultural crops. Whereas food security is the main concern of most resource-poor farmers, they are trying to maximise the profitability of their limited land resources by adopting high-value horticultural crops in hopes of improving their livelihoods. Unfortunately, the lack of technical assistance from national and international institutes for non-traditional crops; and endemic nature of the whitefly problem, has meant the ruin of many resource-poor farmers who have attempted to diversify their subsistence cropping systems.

We describe here the results of the validation of some of the most promising whitefly control (IPM) practices observed in Phase I, in two ‘pilot sites': the Valley of Zapotitan, El Salvador, and the state of Yucatán, Mexico. Basic socioeconomic and biological data were generated in order to determine the magnitude of the whitefly problem and select suitable IPM strategies to meet the needs of small-scale farmers in this region. The *ex ante* data collected showed that most small-scale farmers have diversified their cropping systems, and that the most limiting problems are the whitefly *Bemisia tabaci* and the viruses it transmits.

In Central America, common bean has been one of the two main staples (together with maize) since pre-Columbian times. This crop was the first food staple affected by whitefly-borne viruses in this region, in the late 1970s. In El Salvador, common bean production had been nearly phased out from traditional bean growing areas, particularly during the dry months of the year, when whitefly populations/geminivirus incidence reaches a peak. The Mesoamerican subproject promoted the adoption of a new common bean line bred for resistance to the whitefly-borne *Bean golden yellow mosaic virus*, the main production problem of this legume in the region. With this new cultivar, released recently as ‘CENTA San Andrés’, common bean production has returned to the Valley of Zapotitán, the main supplier of common bean to San Salvador, the capital of El Salvador.

In the case of tomato and peppers, the main horticultural food crops affected by whitefly-borne viruses in this region, there is practically no crop improvement programs in Latin America (despite being the center of origin of these crops). The TWFP evaluated physical control strategies against the whitefly *B. tabaci*, namely: insect-proof nets or 'fleece', that protect susceptible annual crops during the first month of their life cycle. The use of physical barriers also contributes to eliminate pesticide abuse and, thus, food and environmental contamination in rural and urban communities. The use of microtunnels during the critical whitefly/geminivirus periods of the year, has once more made possible and profitable the production of tomatoes and peppers in El Salvador, Mexico and other neighbouring countries that are already adopting this

IPM strategy. Yields of over 40 MT/Ha have been obtained at a time when tomatoes cannot be planted due to whitefly attacks, generating profits in excess of £ 5,000/Ha.

In El Salvador, the Mesoamerican subproject addressed gender issues by incorporating women into a small project on whitefly management of a high-value, perennial horticultural crop (loroco), usually tended by women in the backyard of their homes. Preliminary results show that the IPM strategy implemented has effectively controlled the pest problems that affected this crop. Potential profits for this crop exceed £ 700/ a tenth of a Ha.

The project has placed considerable emphasis on farmer education to eliminate one of the main problems associated with whitefly pests: pesticide abuse. Pesticide abuse results in the elimination of beneficial bio-control agents, emergence of pesticide-resistant whitefly populations, increased production costs, contamination of the environment and food products for the local and export market, and chronic health problems in rural communities.

Background

Whiteflies were declared the pest of the XXth century because of the severity of the damage they inflict directly or indirectly (as vectors of plant viruses) to a multitude of important food and industrial crops around the globe. Despite considerable research conducted in developed and developing countries to control this pest, crop loss is still a common occurrence in tropical regions where small-scale farmers do not receive technical assistance, other than the biased assistance they get from agrochemical companies. This situation has led to crop abandonment, chronic poverty, considerable pesticide abuse, and high levels of food/environmental contamination in developing countries.

As mentioned before, of all the regions in the world affected by the whitefly *Bemisia tabaci*, Central America, southern Mexico and the Caribbean (Mesoamerica) constitute the region with the largest number of crops damaged by this insect, both as a direct pest and vector of an even larger number of plant viruses (geminiviruses or, more specifically, begomoviruses). **Figure 1** and **Table 1** show the areas affected by the whitefly *B. tabaci* and the numerous viruses that this insect vector transmits. These areas are usually located in the most fertile and agriculturally suitable land found between sea level and 1,000 meters of altitude in the entire region, from northern Mexico to Panama, and throughout the Caribbean Basin. Of the various food staples native to this region (*e.g.* maize, common bean, several cucurbits, tomato, sweet pepper and chillies) most have been attacked by whiteflies. Common bean, tomato, sweet pepper and chilli production has practically ceased in the main agricultural areas shown in **Figure 1**, during the prolonged dry season (November-April), due to the large whitefly populations that develop at that time of the year.

Table 2 shows the impact of whitefly-related problems in one of the main agricultural areas of El Salvador, the Valley of Zapotitán, considered the 'pantry' of the capital city of San Salvador. The abandonment of prime agricultural land due to the high incidence of whitefly-transmitted viruses, occurred in all of the Central American and Caribbean countries, and all the agricultural states of Mexico, wherever *B. tabaci* can thrive.

Table 1. Whitefly-transmitted viruses (begomoviruses) present in Middle America.

Virus	Acronym	Main Region Affected
Bean calico mosaic virus	BCaMv	Mexico
Bean dwarf mosaic virus	BDMV	Nicaragua
Bean golden yellow mosaic virus	BGYMV	Entire region
Cabbage leaf curl virus	CaLCV	Jamaica
Calopogonium golden mosaic virus	CalGMV	Costa Rica
Chino del tomate virus	CdTV	Mexico
Cotton leaf crumple virus	CLCrV	Mexico, Guatemala
Cotton yellow mosaic virus	CYMV	Dominican R., Guatemala
Cucurbit leaf curl virus	CuLCrV	Mexico
Jatropha mosaic virus	JMV	Puert Rico
Malvaceous chlorosis virus	MCV	Entire region
Okra mosaic Mexico virus	OkMMV	Mexico
Papaya leaf curl virus	PaLCV	Panama
Passiflora leaf mottle virus	PLCV	Puerto Rico
Pepper golden mosaic virus	PepGMV	Mexico, C. America
Pepper huasteco yellow vein virus	PHYVV	Mexico
Pepper mild tigre virus	PepMTV	Mexico
Soybean golden mosaic virus	SGMV	Caribbean, C. America
Squash yellow mild mottle virus	SYMMoV	Costa Rica
Tobacco apical stunt virus	TbASV	Mexico
Tobacco leaf rugose virus	TbLRV	Cuba
Tomato dwarf leaf curl virus	TDLCV	Jamaica
Tomato golden mottle virus	TGMoV	Guatemala
Tomato leaf curl Nicaragua virus	TLCNV	Nicaragua
Tomato leaf curl Sinaloa virus	ToLCSinV	Mexico, C. America
Tomato mosaic Havana virus	ToMHV	C. America, Cuba
Tomato mottle Taino virus	ToMoTV	Cuba
Tomato mottle virus	ToMoV	Mexico, Caribbean
Tomato severe leaf curl virus	ToSLCV	C. America
Tomato yellow dwarf virus	ToYDV	Jamaica
Tomato yellow leaf curl virus	TYLCV	Caribbean, Mexico

Figure 1. Areas affected by whitefly-transmitted viruses in Mesoamerica.

As suggested by the data presented in **Table 2**, the main impact of whitefly-transmitted viruses took place in the 1990s, although whitefly-transmitted diseases, such as bean golden yellow mosaic, were already important food production constraints in this region prior to 1980. Different factors contributed to the exponential increase in whitefly-transmitted viruses. First, Latin America plunged into an economic depression (known as the 'lost decade' of the 1980s), caused by the mounting external debt of the region. Secondly, Latin American governments saw their traditional export crops (*e.g.* coffee, sugar, bananas) lose value relative to manufactured industrial imports, and thus resorted to non-traditional export crops (NTECs), mainly horticultural (*e.g.* tomato, peppers, cucurbits) and industrial (*e.g.* soybean) crops. Third, these changes took place at a time when the profound economic crisis and austerity measures imposed on Latin American governments by the International Monetary Fund, which resulted in the downsizing of National Agricultural Research Institutions (NARIs), which could no longer provide technical assistance to growers of NTECs. Fourth, this vacuum was rapidly filled by the agrochemical companies; which resulted in widespread pesticide abuse, and, ultimately, high levels of pesticide residues in NTECs and traditional food crops, and resistance to most commercial insecticides in whitefly populations. As a consequence, contaminated produce could not be exported and the saturation of local markets and high production costs, put an end to the hopes of small- and medium-scale farmers to improve their livelihoods by producing high-value crops.

Table 2. Evolution of land use in the valley of Zapotitan, El Salvador, during the dry season (1989-1999).

Crop	1989	1999
Maize	465 has	780 has
Common Bean	175 has	3 has
Tomato	153 has	3 has
Pepper/Chilli	35 has	1 ha
Cucumber	64 has	68 has

From the biological point of view, two main factors further contributed to the emergence of new whitefly-transmitted viruses: first, the diversification of crops (higher number of whitefly hosts), and, secondly, the introduction of a more aggressive and prolific whitefly biotype (B) in the Americas, in the early 1990s.

Central America, Mexico and the Caribbean constitute a region greatly dependent on agricultural products to satisfy its food demand and need to generate foreign income from traditional and non-traditional export crops in order to pay an ever increasing external debt that demands more than half of the Gross Regional Product. For instance, the external debt of Central America grew from US $ 8.5 billion in 1979, to US 20.7 billion in 1985. In that year, Central America was spending over 40% of the revenues derived from the export of goods and services to pay the external debt, and this figure is even higher (>50%) today. Currently, over half of the population of Central America, Mexico and the Caribbean are considered as poor, and 58% of these poor people live in rural areas and work in farming units under 3 has. The dwindling prices of traditional agricultural commodities and the increasing demand for horticultural products in North America during the winter season, creates a potential market for most Middle American countries. When high-value crops (e.g. tomato, pepper, chilli, melon, eggplant, okra, snow pea, broccoli, etc) were introduced in traditional agricultural areas to supply the North American markets, a series of problems emerged. Most of the new crops corresponded to varieties created in temperate countries and, therefore, were not adapted to the tropical and sub-tropical conditions characteristic of Middle America. The intensive use of pesticides applied as a risk-aversion strategy, eliminated most biological control agents for the whitefly *B. tabaci*, giving rise to large whitefly populations, most of which had developed resistance to the traditional insecticides used. Pesticide abuse led to increasing levels of pesticide residues being detected in NTECs, which, together with high production costs, collapsed the agro-export business. These were the main reasons why susceptible crops, such as tomato, pepper, chilli, eggplant, okra and melon, were abandoned in many regions during the dry season.

During Phase I of the TWFP, 11 countries in Central America, the Caribbean Basin, and Mexico, were surveyed to determine the importance and socio-economic impact of the whitefly and geminivirus problems in their main agricultural areas. The survey also included case-studies in selected regions of Guatemala, El Salvador, Honduras and Costa Rica. The data collected clearly showed that every country surveyed had severe whitefly/geminivirus problems, mainly affecting common bean (one of the two main staples in the region) and vegetables, namely tomato, sweet pepper, chillies, several cucurbits, eggplant, and industrial crops such as tobacco. The case-studies confirmed that farmers considered whiteflies as the number one production problem and the main cause for crop failure and significant economic losses.

The extensive surveys undertaken in the region, allowed the TWFP to identify the crops affected; whitefly species and biotypes involved; whitefly-transmitted viruses in the region; and the environmental factors that condition whitefly outbreaks. Moreover, the TWFP could observe all of the IPM tactics employed throughout the region and their potential contribution to whitefly/begomovirus management.

Project Purpose

The purpose of the TWFP-Mesoamerican subproject is to help small-scale farmers diversify their cropping systems and improve their livelihoods by providing technical assistance to manage whitefly-related problems affecting traditional and high-value non-traditional crops in Central America, Mexico and the Caribbean.

Once the geographic dimension, socioeconomic importance, and biological factors conditioning whitefly/virus outbreaks were analysed in Phase I, Phase II undertook the evaluation of the most promising IPM measures available, in selected 'hot spots' of Middle America. The specific purpose of these evaluations was to select IPM packages for the management of whiteflies and whitefly-borne viruses in common bean and horticultural crops in this region.

A major thrust of the project is to eliminate pesticide abuse associated with whitefly control in all crops affected, and thus reduce the levels of pesticide residues in food and horticultural crops in rural and urban areas of Middle America. Ultimately, the adoption of the IPM measures recommended by the TWFP should increase the profitability of mixed cropping systems and improve the livelihood of for resource-poor farmers.

Research Activities and Results: El Salvador

Phase II of the Mesoamerican TWF subProject included two pilot sites: the valley of Zapotitan, in El Salvador, located approximately 35 Km west of the capital city San Salvador **(Figure 2)**, at 460 m above sea level, precipitation of ca. 1,700 mm, and an average annual temperature of 27° C. This valley has an irrigation district (1,813 has) with an annual planting capacity of approximately 4,695 has (over 70% of the farming units are under 4 has), divided into three planting seasons. However, the second most important planting season (December-April) in terms of area planted (over 2,100 has), has been drastically reduced in the case of common bean and vegetable plantings, due to the whitefly/geminivirus problems **(Table 2)**. Thus, this valley, considered as the main food supplier for the capital city, has not been able to fulfil expectations, and, thus, food must be imported (e.g. In 2002, 41,416 MT of red-seeded beans worth US $ 9,404,192; and 41,418 MT of tomato, worth, 7.7 million dollars, were imported) to sustain the demand of San Salvador during the dry months of the year. The TWFP responded to internal policies adopted by the Government of El Salvador to recover this valley to food production during the dry season, by inserting the project into the national agricultural research priorities set by the Ministry of Agriculture (MAG) and its National Centre of Agricultural and Forestry

Technology (CENTA), as stated in their Strategic Plan for 2000-2004. This document reads “the official plan (called ‘Alliance for Work’) has the objective of increasing the production levels and productivity of the agricultural sector, so that it contributes to higher levels of employment and income, and, therefore, to reduce the existing poverty levels, specially in the rural families”. The document states that “the agricultural sector of El Salvador includes over 60% of the economically active labour force of El Salvador, and population-wise, this sector represents the largest number of nationals of any of the productive sectors of the nation”. The plan clearly acknowledges that: “the production of traditional crops is weakened despite improvements in their productivity, due to a decreasing price for these commodities in the international market”. An states that “the comparative advantage of El Salvador and other Central American countries lies in their biodiversity and tropical climate, which permit the production of certain crops, such as fruits and vegetables, during the winter season of North American and European countries”. Unfortunately, the period between November and December, when there is a demand for those products in the north, coincides with the peak of whitefly populations and begomovirus incidence in the Central American and Caribbean regions, as well as in southern Mexico. The agricultural sector of El Salvador has been decreasing its contribution to the Gross Domestic Product (-0.6%) since 2000.

Figure 2. Pilot site (red star) in the Valley of Zapotitán, El Salvador.

El Salvador was also chosen because it was represented by the largest number of institutions willing to collaborate in Phase I. These included: The Ministry of Agriculture, the National Program CENTA, the University of El Salvador, the Latin American Technical University of San Salvador, The Zapotitan Farmer Association (AREZA), private companies and NGOs.

I. Socioeconomic and biological characterisation of pilot site.

The first set of activities initiated in 2001-2002, was designed **to characterise *the ex ante* socio-economic situation** of these target regions. In El Salvador, a questionnaire was designed specifically for the project with the help of the Socio-Economics Unit of the Salvadorean National Agricultural Research Program (CENTA) and given to 62 family units in the valley of Zapotitan.

In the Valley of Zapotitan (3,020 has), El Salvador, as in the rest of Latin America, most of the farmers interviewed were males (96.8%); 66% of whom, have farms under 3.5 has. Common bean was the predominant crop until the late 1980s, but the high incidence of whiteflies and whitefly-transmitted viruses during the dry season, greatly reduced the area planted to this crop in Zapotitan **(Table 1)**. According to the survey, over 40% of the farmers interviewed have abandoned the cultivation of this legume staple because of problems related to the presence of the whitefly/bean golden yellow mosaic. In reference to tomato and pepper/chilli, 67% and 41% of the farmers interviewed had abandoned these crops, respectively. Pests, particularly the whitefly/virus complex, were mentioned by over 52% and 37.5% of the farmers as the main production problems influencing their decision to abandon tomato and peppers, respectively.

A total of 93% of the farmers mentioned that they had abandoned the above-mentioned crops in one of the two main seasons of the year. In the case of tomato and pepper/chilli, 79-82% of the farmers interviewed mentioned the dry season, and the whitefly/virus problems as the main cause. In the case of common bean, 49% of the farmers said that they had abandoned the cultivation of this legume during the dry season, and a similar proportion had desisted planting the crop during the rainy season. The causes for their decisions were 1) the whitefly and 2) fungal/bacterial diseases and flooding problems, respectively. Other problems mentioned, were: price fluctuations, theft and climate change. However, 32% of the farmers interviewed had problems marketing their produce. **Table 3** shows the main market outlet for the different crops analysed here.

Table 3. Main market outlets for agricultural products analysed-Zapotitan.

Crop	Farm	Market Place	Local Stores	Household
Common bean	57.7%	33.5%	0%	6.9%
Tomato	18.2%	9%	54.4%	9.2%
Pepper/Chilli	52.6%	13.2%	34.2%	5.3%
Loroco	16.6%	9.1%	8.2	0.2%

Approximately 37% of the farmers interviewed derived some income from other sources, such as animal husbandry, agricultural machinery rental, commercial activities, and retirement pensions. Interestingly, only 40% of the farmers consulted, kept records of their crop production costs. In tomato, 54% of the production cost corresponds to chemical inputs, both during the dry and rainy season. Although production costs are 36% higher for tomato during the rainy season, yields are also 43% higher during this season. However, prices during the rainy season may drop as much as 84% when compared with summer prices. *Hence, the importance of producing tomato and other high value horticultural crops during the dry season*.

These trends are similar for most agricultural products affected by whiteflies and whitefly-transmitted viruses, although price fluctuations are not as marked for traditional commodities, such as common bean. The insistence of small-scale farmers with risky horticultural crops is based on the fact that 0.1 ha of a crop like tomato, yields a net profit at least twice than that obtained from a whole ha of a subsistence crop such as common bean or maize.

Contributors: Evelyn Osorio (CENTA), James Garcia (CIAT).

Biological Characterisation: *'Investigation on the potential role of different crops as reproductive hosts of the whitefly Bemisia tabaci in the Valley of Zapotitan.'*

The main whitefly species in the lowlands and mid-altitude valleys of El Salvador has traditionally been *Bemisia tabaci*. The first report of *B. tabaci* as a pest and vector of plant viruses in El Salvador was made in 1960, affecting cotton, kenaf and common bean. In the early 1990s, the new biotype B of *B. tabaci* appears in the Caribbean and Mexico, and the TWFP starts monitoring the composition of *B. tabaci* biotypes in El Salvador. Towards the end of Phase I (1998-1999), the presence of biotype B of *B. tabaci* is detected in El Salvador, feeding on chilli (*Capsicum* spp.), loroco (*Fernaldia pandurata*), and various cucurbits (melon, watermelon, cucumber and *Cucurbita moschata*, locally known as 'ayote'). Phase II of the project has paid particular attention to the **evolution of *B. tabaci* biotypes** in El Salvador, as evidence from other countries affected by the B biotype, suggests that the original (A) biotype may be displaced from agricultural regions by the more prolific and aggressive B biotype.

In El Salvador, during phase II, a total number of 18,428 whitefly individuals were collected on different crops for further identification and population analyses. Results (166 assays) obtained until 2003 with a representative sample of whitefly individuals associated with 12 different crops (common bean, soybean, tomato, cucumber, pipian (*Cucurbita argyrosperma*), eggplant, ayote, cabbage, cauliflower, radish, watermelon and loroco, demonstrated the presence of the B biotype of *B. tabaci* in 100% of the samples assayed using the SCAR technique. However, the original (A) biotype was also present in approximately 25% of the samples tested. This year, an analyses of the biotypes found in six different crops (ayote, pipian, eggplant, chipilin (*Crotalaria* sp.), cucumber and tomato) grown in the Valley of Zapotitan, revealed the presence of only the B biotype of *B.* tabaci. These results suggest that the B biotype is gradually displacing the A biotype of *B. tabaci* in the valley of Zapotitan.

Although the collection of whiteflies and analysis of data are not finished yet, **Figure 1** provides a preliminary picture of the potential of some crops as hosts to whiteflies, mainly *B. tabaci*. Fortunately, soybean is not widely cultivated in Central America, as is the case in South America, where soybean is the most important reproductive host of the whitefly *B. tabaci*. The high population of *B. tabaci* found on common bean plants reflects more the condition of this plant species to act as a feeding host, rather than as a reproductive host of *B. tabaci.* In 2001, we observed *B. tabaci* populations of approximately 200 adults per bean plant in 2001, in Zapotitan, but even populations of 5 adult *B. tabaci* per bean plant could result in high rates of BGYMV transmission. A high incidence of whitefly adults per plant usually results in plant death due to feeding damage and development of sooty mould.

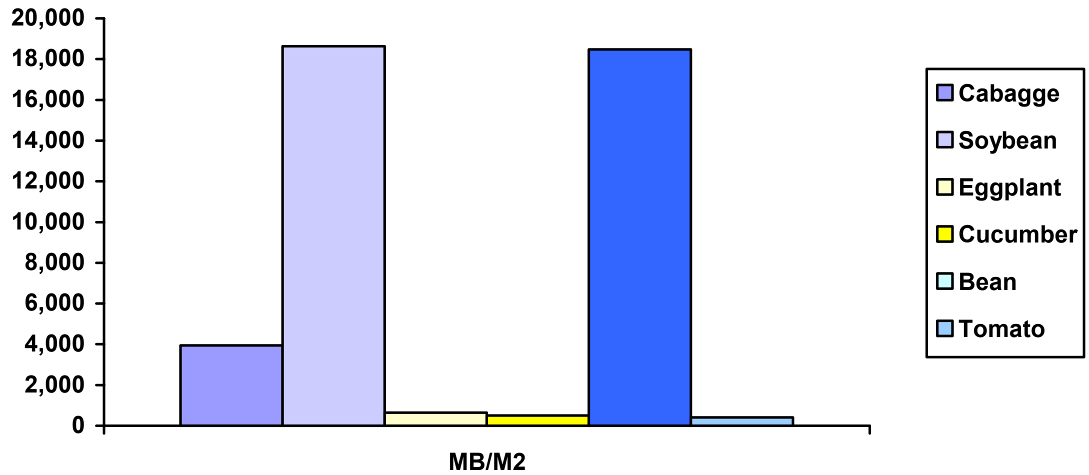

Figure 1. Whitefly adults/m2 on Selected Crops.

We have also observed very high populations of *B. tabaci* on eggplant in the Valley of Zapotitan, but there are no viruses transmitted by this whitefly species in this area. However, eggplant can be affected by sooty mould in this valley. This investigation constitutes the M.Sc. thesis research of the principal investigator at the University of El Salvador.

The **characterization and biotyping of whitefly specimens** is a continuous activity at CIAT, where hundreds of specimens are examined every year by a qualified taxonomist (Ms. María del Pilar Hernández) working part-time for the TWFProject (on USAID funds). All *B. tabaci* specimens are sent to the Virology Laboratory at CIAT for molecular biotyping, using the RAPD (Random Amplified Polymorphic DNA) and SCAR (Sequence Characterized Amplified Region). The latter technique was entirely developed at CIAT by the TWFP in order to simplify the identification of biotype B of *B. tabaci* (**Figure 2).**

These data have been geo-referenced, so that the TWFP and collaborators can monitor the composition of *B. tabaci populations*, as biotype B continues to displace the original (A) biotype **(Figure 3).**

In the case of **whitefly-transmitted viruses** in the Valley of Zapotitán, *Bean golden yellow mosaic virus* (BGYMV) was first reported in 1964, and this tentative identification was confirmed at CIAT in 1992, as the predominant BGYMV isolate in Central America and the Caribbean. In 1998, the TWFP re-confirmed the predominance of this virus in El Salvador, but demonstrated changes in its antigenic properties, probably in response to the arrival of the new *B. tabaci* biotype (B). This situation has remained unchanged, and only a broad-spectrum BGYMV monoclonal antiserum developed by CIAT and the University of Florida, is able to detect the virus.

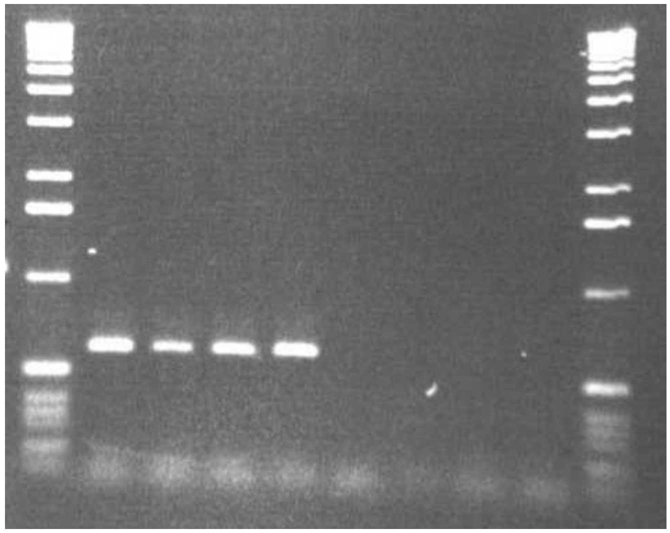

Figure 2. **Sequence Characterised Amplified Region (SCAR) technique developed at CIAT to specifically detect bioty B of the whitefly *Bemisia tabaci*. Extreme lanes: Molecular Markers (1Kb); Lanes 2-5: Biotype B of *B. tabaci*.**

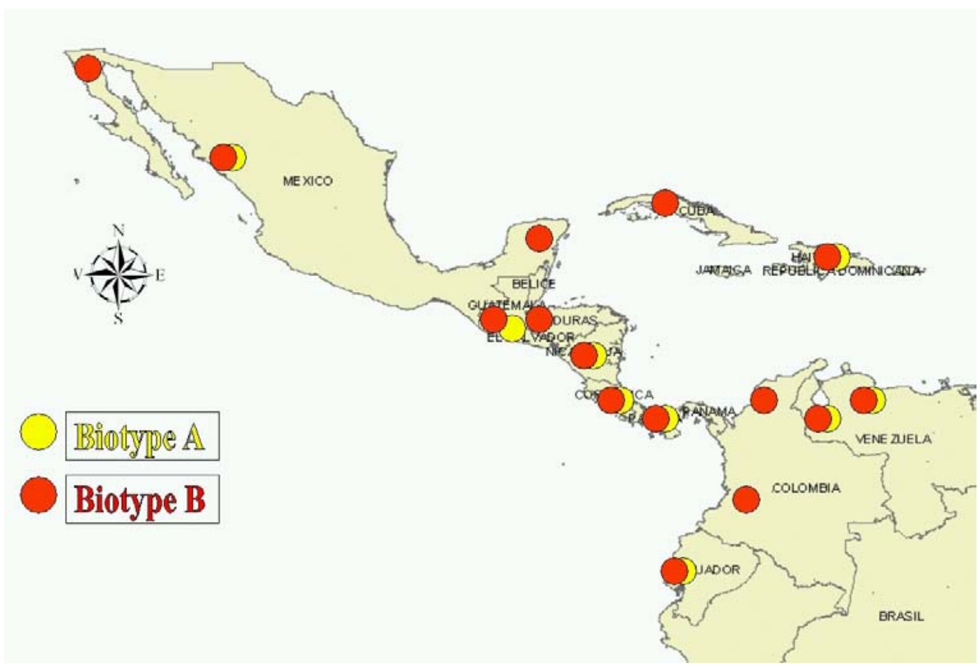

Figure 3. Distribution of *B. tabaci* biotypes A (yellow) and B (red) in Mesoamerica.

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Molecular characterisation of begomoviruses.

During Phase II, other whitefly-transmitted viruses have been detected in peppers, tomato, and loroco (*Fernaldia pandurata*). Different infected samples of these crops have been assayed by PCR, cDNA cloning, and partial sequencing for identification **(Table 4A)**. Some diseased plant samples were shown to be infected by potyviruses, probably transmitted by aphids **(Table 4B)**. This project has achieved the first characterization of viruses affecting loroco in Central America, which made possible the implementation of simple IPM measures to control these viruses, their vectors and pests, such as the whitefly *B. tabaci*.

Table 4A. Begomoviruses identified in horticultural crops in the valley of Zapotitan, El Salvador.

Crop	Begomoviruses
Tomato	Tomato dwarf leaf curl virus
Tomato	Tomato severe leaf curl virus
Pepper	Pepper golden mosaic virus

Table 4B. Other viruses detected (Poty-/Cucumo-viruses).

Tomato	Tobacco etch virus
Pepper	Pepper mottle virus
Loroco	Loroco mosaic potyvirus
Loroco	Loroco foliar distortion cucumovirus

Whitefly population dynamics are also under study and analysis since 2001-2002, when large populations were present on most crops. Whitefly populations were only moderate in the 2002-2003 due to late rains and cold fronts ('nortes') at the end of 2002 **(Figure 4).**

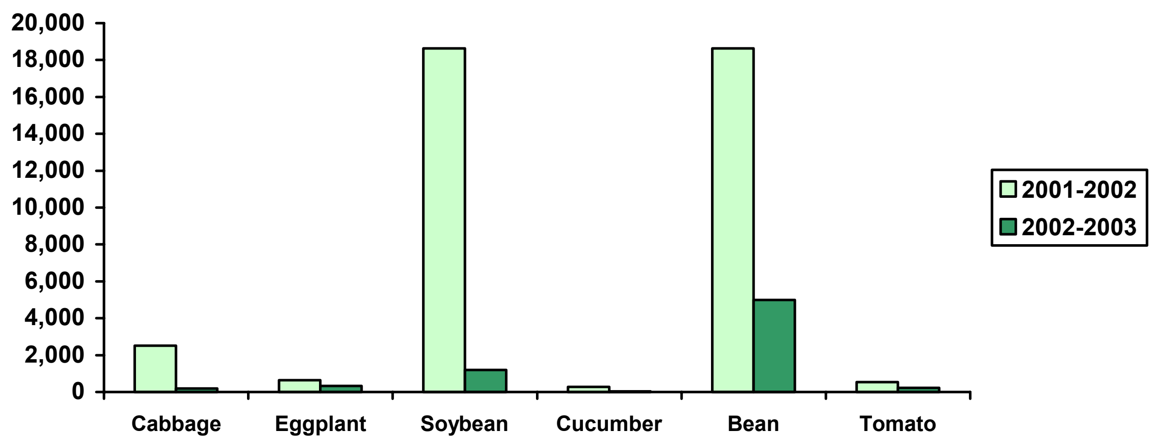

Figure 4. Seasonal variation in whitefly populations – Zapotitan.

Contributors: Francisco J. Morales and Ana Karina Martinez (CIAT).

II. Implementation of IPM measures.

Common bean: '*Recovery of common bean production in the Valley of Zapotitán'*.

Justification: Until 1985, the Valley of Zapotitán was the main common bean production area to satisfy the demand of the capital city of San Salvador, to consume mainly during the months of April, May and June, which come after the end of the prolonged dry season (November-March). The increasing incidence of *Bean golden yellow mosaic virus* (BGYMV), transmitted by the whitefly *B. tabaci*, gradually led to the abandonment of common bean production in this valley during the dry season. Although common bean is produced throughout Central America, the Salvadoran market demands a unique red-seeded bean type ('Rojo de Seda') only produced in this country. Thus common bean imports from neighbouring countries, did not satisfy the consumers and common bean prices and consumption fell (from 12 to 8 kg/*per* capita) since 1985. In 1990, the collaborative project (PROFRIJOL) between CENTA and CIAT, led to the selection of a BGYMV-tolerant common bean variety (CENTA-Cuzcatleco). However, the commercial characteristics of this new variety were not adequate and, consequently, its market price was relatively low. Moreover, the BGYMV resistance of CENTA-Cuzcatleco has been breaking down even during the rainy months of the year, which has further contributed to its rejection by local farmers due to its high protection costs. Hence, the TWFP and CENTA initiated activities towards the identification and validation of new improved common bean genotypes for the San Salvador market.

Research plan: A promising red-seeded common bean line possessing high levels of BGYMV resistance and adequate commercial characteristics was identified in field trials of materials developed by Dr. Juan Carlos Rosas, breeder of the Pan American School (ZAMORANO) in Honduras using parental materials selected through the PROFRIJOL project. The line selected, EAP 9510-77, was planted in September 2001, in five plots of 2,000 sq/m each, to cover the five districts of the Valley of Zapotitán. Half of the area was planted to the local susceptible common bean landrace, 'Rojo de Seda', and the other half with the new EAP line. The plots were planted and evaluated with local farmers in each district. The treatments consisted of minimum inputs: seed treatment (imidacloprid) and herbicide (Prowl). Yield was estimated per plant and per plot **(Table 5)**.

Table 5. Comparative yield (kg/ha) of a new virus-resistant breeding line and the preferred local common bean landrace in the valley of Zapotitán, El Salvador.

Zone	1	2	3	4	5	Average
Year	2001	2001	2002	2002	2003	2004
Virus Inc.	8	8	4	4	6	6
Rojo de Seda	120	150	350	408	230	**251.6**
EAP 9510-77	810	890	1.250	1.400	910	**1,052**

A demonstration plot was planted in 2001 in order to show farmers the superior yielding capacity of the new line EAP 9510-77, as compared with the previous cultivar CENTA-Cuzcatleco (DOR 364) and the preferred landrace 'Rojo de Seda' **(Figures 5 and 6)**. DOR 364 was a CIAT-bred, virus-resistant cultivar released over a decade ago, and although its seed colour was more purple than red, it was widely planted in various Central American countries. This cultivar is on its way out because of its increased susceptibility to BGYMV and dark red colour. The EAP line has a combination of different sources of BGYMV-resistance and better seed colour. Given the clear preliminary results obtained in the first series of evaluation sites, which demonstrate that it is possible to grow common bean during the dry season (November-March) in the Valley of Zapotitán using minimum inputs, line EAP 9510-77 was evaluated at the national level by CENTA with complementary funding from DFID/PROFRIJOL/CRSP-USAID

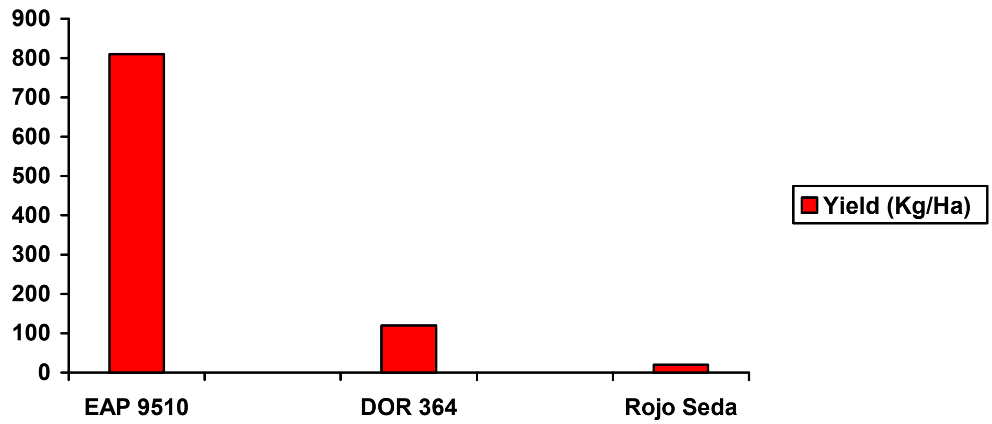

Figure 5. Yield (Kg/Ha) of selected Common Bean Cvs in El Salvador.

Figure 6. Comparison of the new EAP common bean line with the local landrace 'Rojo de Seda,' under BGYMV pressure in the field.

A **case study** was conducted with 60 farmers in the western (6), central (23), para-central (22), and eastern (9) regions, during the second semester of 2003. Only 3 of the 60 farmers interviewed were women, which reflects the cultural characteristics of farming in Latin America. The age range of the farmers interviewed was 30-81 years, with 60% of the farmers being older than 50 years. This finding illustrates the migration of young people from rural to urban areas in search of jobs in commerce, industry and maquila, all activities that show positive growth in recent years, as well as an increase in minimum wages. Interestingly, 92% of the farmers interviewed were literate, although only 22% reached secondary school. Over 70% of the farmers owned their farms and 58% lived in the farm. 75% of the farmers do not have access to credit and most farmers have incomes between US $ 1.50 and 3.00/day.

The area of the validation plots varied according to the capabilities and willigness to collaborate of the participating farmers, from 200 sq/m to 1,750 sq/m for the new line, and from 200 sq/m to 2,598 sq/m for the local check (red-seeded cultivar chosen by the farmer).

Farmers also differ in relation to the cropping system used: monoculture (42%), association (20%) and relay (38%). The most popular common bean cultivars are: Rojo de Seda (30%), followed by two BGYMV-resistant cultivars (CENTA 2000 and DOR 585). 80% of the participating farmers registered higher yields with the new improved common bean EAP line. Only in the central region approximately 20% of the farmers concluded that they preferred their traditional bean cultivar. 62% of the farmers manifested that the new line had superior disease resistance qualities as compared to their own cultivars. 33% could not tell any difference (mainly those that already grow virus-resistant cultivars, such as CENTA 2000 and the DOR lines), and 5% concluded that the new material was more susceptible. However, it was later shown that the susceptibility of the new line was to ‘web blight’, a fungal disease present in isolated areas of El Salvador. 83% of the farmers considered that the commercial characteristics of the EAP line as excellent. The remaining 7% thought that their local material was better (mainly the local landrace ‘Rojo de Seda’ which is highly susceptible to BGYMV and cannot be grown in the dry season even under heavy chemical protection).

The most important result of this survey is that 87% of the farmers that planted the new improved bean line were willing to adopt it. This figure was almost 100% in areas affected by the whitefly-transmitted BGYM virus. Of all the seed obtained by the collaborating farmers, 37% was used for household consumption, 32% was saved as seed for the next planting, and 27% was sold to generate income.

Table 6 shows the statistical analysis of the different variables evaluated in order to determine the level of acceptance of the new line EAP 9510-77.

Table 6. Main variables that determine the adoption of a new bean cultivar.

Variable	Coefficient	Standard Error	t-Statistic	Probability
Intercept	0.141624	0.260788	0.543063	0.5895
Growth Habit	0.14294	0.120277	1.188416	0.2403
Vegetative Cycle	0.115406	0.075519	1.528176	0.1328
Yield	-0.115342	0.087253	-1.321933	0.1922
Disease R	-0.166001	0.099686	-1.665248	0.1021
Pest Resistance	0.101755	0.097583	1.042755	0.3021
HumidityTolerance	0.053299	0.049807	1.070111	0.2897
Market Price	-0.057198	0.054633	-1.04696	0.3002
Acceptance	0.693283	0.156329	4.434778	0.0001
R^2	0.376418	Mean dep. var.		0.881356
Adjusted R^2	0.276645	S.D. dep. var.		0.326145
St. Error Regress.	0.277387	F value		3.772743
Residual S.C.	3.847183	Probab (F)		0.001584

Model: Varietal Adoption = 0.141624 + 0.14294 contall + 0.115406 cveg-0.115342 rend-0.166001 resenf + 0.101755 respla + 0.053299 tolhum-0.057198 sale + 0.693283

Table 7 shows the superior yielding capacity of the new material EAP 9510-77 in the selected regions where it was evaluated, in relation to the local cultivar.

Table 7. Results of the validation trials of EAP 9510-77 in 4 regions of El Salvador.

Region	EAP 9510-77	Local cvar.	Yield Difference	Percentage
West	1815 kg/ha	1312	503	27.7
Central	1259 kg/ha	951	308	24.5
Para-Central	1088 kg/ha	875	213	19.6
East	1171 kg/ha	901	270	23.0
National Av.	1240 kg/ha	952	288	23.2

The line EAP 9510-77 was officially released in November 2003 as the new variety 'CENTA San Andres'. In the District of Zapotitán, the TWFP (DFID) has financed two field days for 83 farmers (including 18 women), and 18 technicians, in order to promote the new variety.

Contributor: Ing. Carlos Atilio Perez (CENTA).

Collaborators: Agents (3) of the Zapotitán Extension Agency (CENTA) under the coordination of Ing. Mario Aragón.

Horticultural crops: '*Management and control of whiteflies using physical barriers to protect tomato and pepper crops in the Valley of Zapotitán, El Salvador'*.

The Ministry of Agriculture and CENTA had manifested the need to recover tomato production in El Salvador, in order to reduce the increasing amount of tomato imports required to satisfy the internal demand. As seen in **Table 1** and as stated by most farmers interviewed for the *ex ante* case study conducted in El Salvador, vegetable production simply became unviable because of the whitefly problem. Two decades ago, the Valley of Zapotitán contained over 280 hectares of tomato, but due to the whitefly problem, the area was reduced to only 35 has in 2000. This situation has forced the Salvadoran government to import 41,418 MT of vegetables in 2002.

The main strategy evaluated in the Valley of Zapotitán during Phase II, was the use of physical barriers (**microtunnels**) for tomato and peppers, using different types of mesh (fleece). Initially, the experimental design contemplated a series of five replications (in the five zones into which the irrigation district of Zapotitán is divided) in paired plots. The evaluation variables selected were: production cost, yield and net benefit. During, the first evaluation conducted at the onset of the dry period in 2001, the experimental design suffered modifications due to various constraints. First, the importation of the material to make the microtunnels was difficult because anti-insect nets were considered a luxury item in El Salvador, which significantly increased the price of the net and prolonged its nationalization. Secondly, some farmers modified the design of the microtunnels to prolong the protection period for the transplanted tomato seedlings, which left some chilli rows uncovered for lack of this imported material. Third, some participating farmers did not control weeds inside some microtunnels, which eventually reduced yields below the economic threshold, and had to be discarded. However, the remaining evaluation plots allowed farmers to appreciate the clear benefits of using microtunnels, in terms of making possible the cultivation of susceptible horticultural crops under high whitefly/virus pressure **(Figure 7)**. This picture shows the effect of high whitefly/virus incidence (as it occurred in the dry season of 2001/2003): the complete destruction of the uncovered rows of tomato. Even the rows protected with the net for over 30 days suffered significant yield loss. In this evaluation, uncovered tomato plants died from the early virus infection, whereas tomato plants protected for up to 30 and 60 days produced 12.8 and 60 MT/ha, respectively. In a second trial, the covered tomato produced 55 MT/ha, whereas the uncovered control produced 15 MT/ha under chemical (imidacloprid) protection **(Table 8)**. The national average during the rainy season is 20 MT/ha.

Cultural practices and physical barriers to the whitefly vector, were complemented with pesticide reduction tactics to lower the amount of pesticide residues in horticultural products for the local markets, and their negative impact on the environment and production costs.

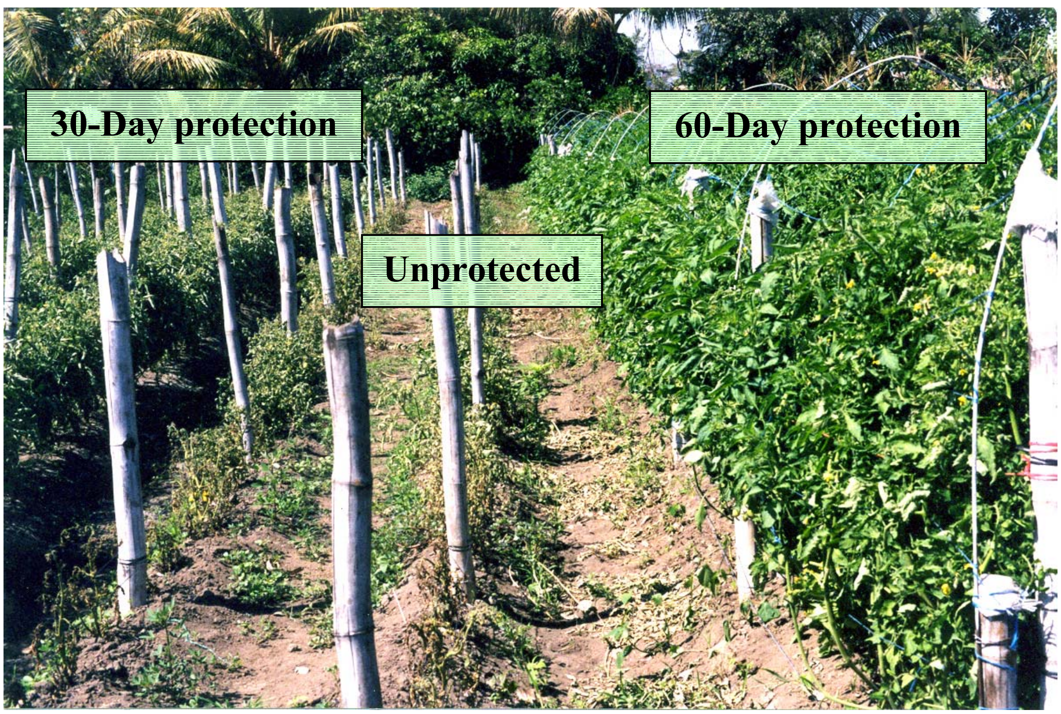

Figure 7. Effect of covering tomato plants for 30 and 60 days after transplant as compared to the uncovered control.

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