CHAPTER 2.7

Conclusions and Recommendations

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Results of Country Studies

Bemisia tabaci (Gennadius) research in the eastern African region has been focused so far on cotton (*Gossypium hirsutum* L.) in Sudan and on cassava (*Manihot esculenta* Crantz) in Kenya, Tanzania and Malawi. In recent years, vegetables have become the crops most severely affected by *B. tabaci*-transmitted viruses. Little attention has been directed to vegetables therefore little information was available prior to the commencement of the System-wide Tropical Whitefly Integrated Pest Management (TWF-IPM) Project in this region. For the first time, information about critical aspects of *B. tabaci* characterization on the vegetable-based cropping system has been reported from the eastern Africa region.

Characterization of begomovirus and whitefly biotypes

B. tabaci is the most dominating whitefly species in the region as a whole. All specimens of whitefly collected in Sudan were *B. tabaci*; in Tanzania, *B. tabaci* made up 78% of the collected specimens and in Kenya, 65%. The species *Trialeurodes vaporariorum* (Westwood), *Bemisia afer* (Priesner & Hosney), *Siphoninus phillyreae* (Haliday), *Aleurothrixus floccosus* (Maskell), *Trialeurodes ricini* (Misra), *Orchamoplatus citri* (Takahashi), *Tetraleurodes andropogon* (Dozier) and *Aleyrodes proletella* (Linnaeus) were occasionally encountered in Malawi, Kenya and Tanzania, of which the last four species were registered for the first time in Tanzania. *Bemisia hirta* spec. nov. was encountered once but is subject to confirmation. *A. floccosus* was encountered on citrus. In the East African highlands, *B. tabaci* was the dominating whitefly species from sea level up to 1300-1700 m above sea level, above which *T. vaporariorum* and *T. ricini* dominated. In southern Africa (Malawi), *B. tabaci* only dominated up to 900 m above sea level, above which *B. afer* was the dominating species.

Disease incidence and symptom severity

The Phase 1 survey revealed silver leaf symptoms on squash (*Cucurbita pepo* L.) in Sudan. Elsewhere, these symptoms are associated with *B. tabaci* biotype-B as the causal pest. This is the first observation of silver leaf symptoms in the region and may indicate that this feared biotype-B has reached Sudan. Characterization of the *B. tabaci* specimens collected at the site where the silver leaf symptoms were found is underway and the biotype-B is yet to be confirmed.

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B. tabaci was found widespread on tomato (*Lycopersicon esculentum* Mill.), pepper (*Capsicum* spp. L.) and eggplant (*Solanum melongena* L.), in the *Solanaceae*; watermelon (*Citrullus lanatus* [Thunb.] Matsum. & Nakai), melon (*Cucumis melo* L), squash, cucumber (*Cucumis sativus* L. var. *sativus*) and bitter gourd (*Momordica charantia* L.), in the *Cucurbitaceae*; common bean (*Phaseolus vulgaris* L.), lablab (*Lablab purpureus* [L] Sweet), *Leguminosae* family; cassava (*Euphorbiaceae*); okra (*Abelmoschus esculentus* [L.] Moench), cotton, sweetpotato (*Ipomoea batatas* [L.] Lam.), *Desmodium* and basil (*Ocimum basilicum* L.), in the *Labiateae*. In addition to these families, *B. tabaci* also was found frequently on wild plant species within the families of *Acanthaceae*, *Amaranthaceae*, *Asteraceae*, *Commelinaceae* and *Verberaceae*.

Whiteflies in association with *Tomato yellow leaf curl virus* (TYLCV) had been studied in the Sudan (Dafalla and Sidig, 1997) and *Tomato leaf curl virus* (ToLCV) symptoms in Tanzania had been found due to a unique strain named ToLCV-Tz (Chiang et al., 1997). Since tomato was known as one of the most profitable crops, and whiteflies had been ranked as the most/second most important pest/vector in tomato (Varela and Pekke, 1995), tomato was selected as the target crop in an extensive survey on whiteflies and whitefly-transmitted viruses (WTVs) in vegetable production in the region.

Tomato yellow leaf curl (TYLC) symptoms have been identified as caused by TYLCV in Sudan, Kenya and Malawi. TYLC/tomato leaf curl (ToLC) symptoms were found in more than 93% of the surveyed fields of tomato in Sudan and Tanzania, in 72% in Malawi and 55% in Kenya. More than 25% TYLC incidence was found in 50% of the fields in Sudan, 34% in Tanzania, 11% in Kenya and 6% in Malawi. In the East African highlands, high ToLC incidence (>70%) was found from 500-1000 m above sea level in Kenya but from 50-1500 m above sea level in Tanzania. TYLC symptoms are particularly severe during the hot seasons (December to March in Tanzania and Kenya; March to September in Sudan).

Reservoirs for TYLCV in the wild vegetation were found in plant species belonging to the families of *Solanaceae* and *Euphorbiaceae*, in particular, and in *Amaranthaceae*.

In Sudan, the experienced team surveyed WTVs in all commonly grown vegetable crops. TYLCV in tomato is by far the most economically important *B. tabaci*-transmitted virus in Sudan. Next ranks *Watermelon chlorotic stunt virus* (WmCSV) and *Okra leaf curl virus* (OLCV). TYLCV and WmCSV are particularly severe during the hot season growing periods (March-September) and OLCV during the late winter and early summer (January-March). Other severe WFTV were *Tomato vein thickening virus* (TVTV) in tomato, *Cucumber vein yellowing virus* (CVYV) and a yellowing-inducing poty-like virus not fully identified in watermelon and musk melon (*Cucumis melo* L.). Less important WTVs, yet representing a potential hazard, are TYLCV in pepper, WmCSV in snake melon (*Cucumis melo* L. subsp. *melo* var. *flexuosus* [L.] Naudin) and squash, a begomovirus and a closterovirus not yet fully identified in *Vigna* sp. and common bean (*Phaseolus vulgaris* L. var. *vulgaris*), *Bean mild mosaic virus* (BMMV) and *Pepper leaf curl virus* (PepLCV).

The African Regional Program (ARP) of the Asian Vegetable Research and Development Center (AVRDC) has identified three tomato accessions

(Fiona, Tyking and TY52) resistant to TYLCV and ToLCV-Tz. Under heavy disease pressure, these accessions are symptomless and the viruses are not detected by DNA hybridization. Furthermore, two tomato accessions (PSR-403511 and PSR-407111) were identified as tolerant to TYLCV; only 5%-9% disease incidence was detected under heavy disease pressure.

Natural enemy species

Encarsia sophia (Girault and Dodd) was the predominant whitefly parasitoid in Kenya, Tanzania and Malawi, but was not encountered during the survey in the Sudan. *Encarsia lutea* (Masi) and *Eretmocerus mundus* Mercet. were predominant in the Sudan but not in the other countries, although *Eretmocerus* spp. were occasionally encountered in Kenya and Tanzania. *Encarsia formasa* (Gahan) was encountered in the highlands of Kenya. Predators of coccinelids, lacewings, bugs, spiders and mites were found adjacent to whitefly populations and their identification at species level is yet to be confirmed.

Estimation of disease incidence and yield losses

In Sudan, the "hot spots" for *B. tabaci* and transmitted viruses are the arid and irrigated cotton-growing areas in Gezira and Khartoum States, at 400-500 m, where the problem is severe throughout the year but peaking in March to September. Where cotton is not grown, the incidence is less. In Tanzania, the hot spots for *B. tabaci* and TYLC are transitional areas in Morogor, Dodoma, Kilimanjaro and Arusha, ranging from 100-1450 m. In Kenya, the hot spots are semi-arid to transitional areas in Eastern Province (Kibwezi, Kitui and Machacos) and Rift Valley (Naivasha), 700-1200 m. In Malawi, the hot spots are in southern areas of the Lake Malawi region (Dedza, Mzimba, Thyolo and Ntcheu), 600-1500 m. In Tanzania, Kenya and Malawi the problem is most severe during the hot dry season, December to March. Irrigation in the semi-arid and arid regions allows for continuous cultivation of crops favoured by *B. tabaci* and transmitted viruses, which guarantees continuous availability of reproductive hosts during the year.

In hot spot areas throughout the region, yield losses due to *B. tabaci* and transmitted viruses ranged between 50% and100%. As an average of all surveyed tomato fields, the yield losses due to *B. tabaci* and TYLC were 49% in Malawi, 45% in Tanzania and 30% in Kenya. In Sudan, the survey revealed that an average of 62% fruit yields of tomato, watermelon, musk melon and okra are lost annually due to *B. tabaci*-transmitted viruses. WmCSV was implicated in up to 80% yield losses of export Galia melon in Khartoum and Gezira States during the 1998-99 season, and completely wiped out the production in southern Blue Nile, Shuwak and Dinder inland delta. In the region in general, more than 65% of producers reckoned that they had whitefly/disease problems in their tomato crop every year and 1997 was the year with the most severe attack (prior to the onset of the El Niño rains). On average, producers in the region spend US$145 per hectare combating whiteflies.

Farmers' assessment of whitefly-related problems

In Sudan, farmers ranked *B. tabaci* and its transmitted viruses as the most economically and most damaging crop protection problem in tomato in the country. In Tanzania, farmers ranked *B. tabaci* and its transmitted viruses as a second problem in tomato after bacterial blight. In Kenya and Malawi, *B. tabaci* and its transmitted viruses ranked less important. Nevertheless, 79% of the interviewed farmers in Kenya found that the problems were on the increase compared with 74% in Tanzania, 68% in Malawi and 65% in Sudan.

It was generally believed that the whitefly/disease complex is most damaging during dry and hot seasons (December through March in Tanzania and Kenya, March through August in the Sudan). In Malawi, however, controversial opinions on the seasonality of outbreaks were found among the interviewed producers. Interestingly, in the Sudan, TYLCV incidence was most severe during the hot summer months despite less prevalence of the vector, whose population peaked during the cooler winter months (December through January).

Pesticide use

Eighty three percent of the farmers interviewed in the region applied pesticides in their tomato crops. The percentage of farmers making more than nine pesticide application per tomato cropping season was 56% in Sudan, 21% in Tanzania, 9% in Malawi and 8% in Kenya. The use of synthetic insecticides was the most prevailing control method and in most cases the producer alone made the decision on what insecticide to use and when (average 84%). Half of the producers sprayed insecticides as a prevention measure and 25% of them would start spraying after damage had been observed. Five to six sprayings per season was practiced on average but in the Sudan, 56% of the interviewed farmers made nine or more applications per season. Pyrethroids and organophosphates were the most commonly used insecticides in the region.

Only 35% of the interviewed producers in Sudan, 11% in Tanzania, 1% in Kenya and none in Malawi knew about the inter-relationship between whiteflies and ToLCV symptoms. In Morogoro in Tanzania, where 100% ToLCV incidence was found on all the surveyed farms, none of the producers knew about its inter-relationship with whiteflies. In Malawi, almost all producers confused TYLC symptoms with other damage such as damage from red spider mite, aphids, heavy rain, fungal diseases, nitrogen deficiency and soil-borne diseases.

Sudan is the only country in the region that has adopted IPM as its official policy of crop protection aimed at combating the whitefly problem. Government support for IPM is well defined in the recent publication, Sudan Country Strategy Note, 1997-2001: Partnership towards Sustainable Human Development. The document emphasizes that the Government of the Sudan is in pursuit of an integrated program for environmentally sustainable development. However, there is at present a laxity in implementation and in cultural and legislative measures. There are no restrictions on the number of pesticide applications. Sudan has no extension service at all, whereas technical advisors from extension services have visited about one-third of the interviewed producers in the other countries.

Strengthened Research Capacity

The TWF-IPM Project has helped in increasing the capacity in whitefly research by training one M.Sc. student from Kenya and one Ph.D. student from Sudan. With assistance/input from the Institute of International Education (IIE), London, and the John Innes

Centre (JIC), project scientists were trained in conventional taxonomy and DNA techniques. A short-term attachment also was completed on the effect of host plants on the oviposition and survival of the sweetpotato whitefly. After long fruitless efforts, finally cultures of *Bemisia* and *Trialeurodes* were successfully established at the International Center of Insect Physiology and Ecology (ICIPE). The Centre, AVRDC and the national partners are planning work on transmission studies and host suitability studies in Phase 2. The hot spot areas of whitefly problems in partner countries have been identified. Besides confirming the local occurrence of several known natural enemies of whiteflies, additional genera/species of predators/parasitoids have been identified. Perceived on-farm losses due to tomato geminiviruses and the average cost to control whitefly/TYLC per hectare of tomato in one season were documented.

ICIPE has extended assistance in the identification of whitefly species and natural enemy collections from surveys across nine countries in Africa to the subproject on whiteflies on cassava and sweetpotato, led by the International Institute of Tropical Agriculture (IITA). Likewise, ICIPE has extended assistance in the identification of whiteflies and natural enemies to countries that were not participating officially in this project, for example, Uganda and Senegal. The Center has established a reference collection for African whiteflies in the past 2 years from 10 countries within the framework of the two African whitefly subprojects. This is in connection with a collection of about 2000 samples of whiteflies and more than 4000 nymph specimens mounted on permanent slides, in addition to about 400 whitefly parasitoids and predators collected. It is hoped that this collection will further help understand whiteflies in future studies and training.

This project demonstrates how effective collaboration can result in proper identification of research agendas and their correct implementation. This has been possible only because of the joint efforts of the national programmes and the collaborators in a well-coordinated approach. The joint efforts of the ICIPE scientists and the national teams have further strengthened ICIPE's partnership with national programmes in Africa. This mode of collaboration and the complementation between ICIPE, AVRDC, JIC and national agricultural research systems scientists has helped link up the expertise of these centres and the local knowledge and experiences of the national programmes. The adoption of a standardized methodology and being able to modify it to suit specific requirements has simplified work and made it possible to compare results and share experiences.

Recommendations

As a result of a joint planning workshop in September 1999, the partners in Sub-project 3 (Whiteflies as vectors of viruses in vegetable and mixed cropping systems in eastern Africa) made the following recommendations for the second project phase.

It was proposed that Phase 2 should include Uganda in addition to Sudan, Tanzania and Kenya. The focus should remain on *B. tabaci* as vector of viral diseases. The target cropping system in Kenya and Uganda will remain tomato. Target cropping systems will include both tomato and watermelon in Tanzania and tomato, cucurbits and okra in the Sudan. There is a need to continue the characterization of whiteflies and WTVs in target cropping systems. This characterization comprehends both characterization at molecular level, including bio-typing of whiteflies, and biological characterization of both whiteflies and WTVs with emphasis on host range, host preferences and interaction between the whiteflies and the viruses.

The aim is to continue strengthening the global whitefly network set up by the TWF-IPM Project. Through this network, scientists from the region will enjoy the information flow of knowledge and participation in experimental research in order to boost the whitefly research in their respective countries with new knowledge and disseminate new control methods to the national extension services and vegetable producers. Initiatives taken to create an African Whitefly Network should continue.

More evidence must be recorded on yield depression due to whiteflies and their transmitted viruses. Geographical information on agricultural regions, major crops, target crops, whitefly/virus hot spots, topographical and climatic data, crop seasonality and spatial patterns of cropping systems must be collected in order to apply geographic information systems to the information created.

There is an urgent need for the immediate development of IPM components viable under the socio-economic conditions in the region. Selection, multiplication and dissemination of tomato varieties resistant/tolerant to whitefly and/or ToLCVs were given first priority in the development of the IPM component. AVRDC should gather and multiply a "package" of resistant germplasm from all over the world and distribute it to the national partners for screening, selection, multiplication and dissemination.

Development of physical barriers for vector control was given second priority in developing the IPM component. Different physical screening methods to prevent early invasion of whiteflies should be gathered from all over the world and tested as physical control measures under the socio-economic and climatic conditions in each partner country.

Testing rational use of conventional and non-conventional insecticides was given third priority in developing the IPM component. Producers urgently need alternative control methods in order to meet the new requirements of pesticide residue-free products for the export market. Regional monitoring of insecticide resistance of whiteflies will provide useful information to convince policy makers of the need for developing alternative control methods. Non-conventional and indigenous methods from all over the world such as oil, non-phytotoxic soaps, botanicals and ash should be gathered in a "package" and tested in partner countries by means of a standardized methodology that will allow comparisons across ecosystems. Evaluation of the effect of both conventional and non-conventional control methods on natural enemies and biological control agents such as parasitoids and entomopathogens will reveal information on their potential environmental impact and their suitability in organic farming.

Understanding of the mechanism behind effective cultural practices in order to define appropriate cropping sequences also was put on the agenda. Such studies may require several years and experimental cropping seasons and may not provide immediate applicable information for producers as the target stakeholders. The priority of such studies was therefore set to follow the above IPM components. Such studies would evaluate the effect of diversity-based cropping in time and space, planting dates, planting density, ground cover, roguing, in-field weed management, crop residue management and micro-environment modification.

Studies on biological control of whitefly vectors were given less priority. Since low vector populations can create a severe virus outbreak, it is believed that biological control may have low impact in the control of virus outbreaks driven by the movement of whitefly vectors. It was decided to start gathering cases of successful legal control methods and related documentation. When sufficient evidence has been provided through the project work, the aim is to start reinforcing official regulation and inspection for area-wide management, including planting date, harvesting date, crop free periods, destruction of crop residues, irrigation cut-off, etc.

The research capacity in the partner countries must be strengthened through training of national scientists in detection, identification and characterization of whiteflies, WTVs, natural enemies of whiteflies and epidemiology. Furthermore, yearly information exchange and co-ordination meetings will be needed.

When feasible, producers must be actively involved in the development of the IPM component, including the brainstorming, planning, realization and evaluation of experiments. Training handouts on rational control of whiteflies and WTVs must be produced for the extension service and producers, and farmers' organizations in hot spot areas must be sensitized, in particular. Decision support tools must be available for policy makers and news media must be used currently as the project develops.

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