Chapter 2.3

Kenya

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Introduction

Geographical context

Field surveys covering 94 farms were conducted in 1997-98 following the methodology agreed among project partners. The farms represented: Kirinyaga, Thika, Muranga, Kiambu, and Nairobi Districts in Central Province; Machakos, Athi River, Meru, Kitui, and Kibwezi Districts in Eastern Province; Kwale, Kilifi, and Taita Taveta Districts in Coast Province; Kajiado and Naivasha Districts in Rift Valley Province; Kisii, Migori, Homa Bay, and Siaya Districts in Nyanza Province; and Vihiga and Busia Districts in Western Province (Figure 1). The districts were selected based on the prevalence of the cultivation of tomato (*Lycopersicon esculentum* Mill.). Table 1 gives the mean annual temperatures and precipitation for each of the surveyed regions.

In the surveyed regions, tomato is planted throughout the year with the exceptions noted below. Eastern Province is a region of semi-arid lower mid-altitude land becoming transitional semi-humid towards Central Province; here, tomato is not planted in July.

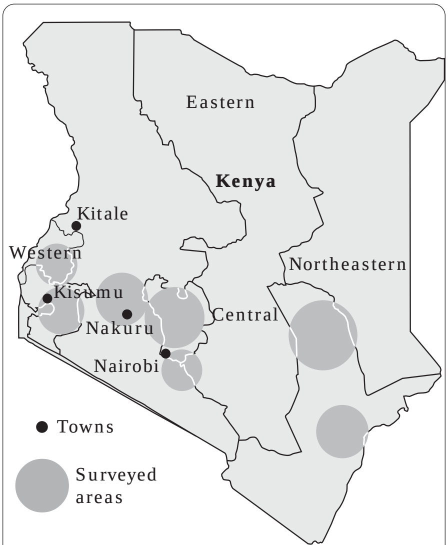

Figure 1. Tomato-growing areas surveyed for whitefly incidence in Kenya.

Table 1. Mean annual temperatures and precipitation for the surveyed regions of Kenya.

Region / Province	Mean min.-max. temperature (°C)	Mean precipitation (mm)
Eastern	15-26	728
Rift Valley	14-27	591
Central	13-25	1166
Coast	21-30	872
Western and Nyanza	16-29	1289

Whitefly surveys took place between November and March of 1997-98 and 1998-99. Rift Valley Province consists

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of transitional lower to higher mid-altitude land. In the surveyed areas of Kajiado and Naivasha Districts in the Rift Valley, tomato is not planted in January and July. Whitefly surveys were carried out in September 1998 and March 1999. Central Province consists of sub-humid highlands; whitefly surveys were carried out here between November and March in 1997-98 and in 1998-99. In the Coast Province, a region of sub-humid coastal lowlands, tomato is not planted from November to January. Whitefly surveys were carried out in July 1998. In Western and Nyanza Provinces (sub-humid to humid upper mid-altitude land and lower highlands) tomato is not planted in January. Whitefly surveys in this region were carried out in February and November 1998.

El Niño rains devastated tomato production in Kenya from September 1997 to June 1998. Whiteflies were scarce during this period.

The emergence of **Bemisia tabaci** *as a pest and virus vector*

Tomato is one of the most widely cultivated vegetable crops in East Africa, predominantly grown by small-scale producers for fresh consumption (GTZ, 1995), while in Kenya in particular, vegetable-growing both for local consumption and for export provides an increasingly important source of income to farmers. In 1995, Kenyan national scientists participating in a regional workshop ranked the whitefly *Bemisia tabaci* (Gennadius) as the most important pest/vector in tomato (Varela and Pekke, 1995). This whitefly has become an important production constraint to crops of the families *Solanaceae*, *Leguminosae*, *Malvaceae*, *Cucurbitaceae* and *Euphorbiaceae*, particularly in the semi-arid Eastern Province of Kenya. Extension workers and scientists have reported informally the occurrence of several whitefly-transmitted viruses: *Tomato yellow leaf curl virus* (TYLCV), *Cowpea mild mottle virus* (CPMMV), *Sweetpotato mild mottle virus* (SPMMV) and *Watermelon chlorotic stunt virus* (WmCSV).

Despite the perceived importance of these horticultural crops and their virus disease problems in Kenya, previously no systematic attempt has been made to document their distribution and incidence. Virtually all work related to whiteflies conducted in Kenya has focused on cassava mosaic disease (CMD), its prevalence in the country, its temporal and spatial distribution and associated yield loss (Seif, 1982; Bock, 1987). Some research also had been conducted on the citrus woolly whitefly *Aleurothrixus floccosus* (Maskell), which is reported to have become a common pest of citrus (*Citrus* spp. L.) as well as coffee (*Coffea arabica* L.) and guava (*Psidium guajava* L.) in Kenya (Löhr, 1997). In addition, the whitefly parasitoids, *Eretmocerus mundus* Mercet. and *Encarsia sublutea* (Silvestri), have been recorded in Kenya (Dr. Abdurabi Seif, personal communication, 1998). Kenya's participation in the Tropical Whitefly Integrated Pest Management (TWF-IPM) Project provided an opportunity to gain an overview of the geographical range and economic importance of whiteflies, whitefly-transmitted viruses and whitefly natural enemies in the country—information that would serve as a sound basis for planning further research and pest management efforts.

Increased Biological Understanding

Characterization of begomoviruses and whitefly biotypes

During the surveys in Kenya, 325 collections of whitefly adults and nymphs were made. From these, 549 specimens of whitefly nymphs were mounted on 310 slides and identified to species level. Most of the whiteflies collected were *B. tabaci* (57%), while *Trialeurodes vaporariorum* (Westwood) represented 34%. *B. afer* (Priesner and Hosney) were occasionally found (7%) in fields of cassava (*Manihot esculenta* Crantz) adjacent to tomato fields. A number of other whitefly species (2%) also were encountered, including *Trialeurodes ricini* (Misra), *A. floccosus*, *Siphoninus phillyreae* (Haliday) and *Bemisia* spp. Table 2 shows the composition of whitefly species based on the identified specimens from each Province.

Disease incidence and symptom severity

Whiteflies in the surveyed farms were found breeding on host plants that belong to the following families: *Acanthaceae, Amaranthaceae, Asteraceae, Commelinaceae, Convolvulaceae, Cucurbitaceae, Euphorbiaceae, Lamiaceae, Leguminosae, Malvaceae, Rutaceae, Solanaceae* and *Verbenaceae* (Table 3). Surprisingly, whiteflies were found breeding only occasionally on tomato in Kenya. In Muranga, Kiambu and Mwea Districts in Central Province, it was difficult to find a single whitefly nymph in a whole tomato field. In these areas, whiteflies, mainly *T. vaporariorum*, were found breeding on crops such as common bean (*Phaseolus vulgaris* L.) and cassava and on non-cultivated plants, most significantly *Euphorbia heterophylla* L., in all areas surveyed. However, in Kihara (Nairobi) and Kigumo (Muranga) in Central Province and in Nguruman in Rift Valley Province, whiteflies, mainly *T. vaporariorum*, were found breeding readily on tomato.

Host plant feeding preference and status as reproductive hosts (oviposition and offspring survival) of *B. tabaci* was studied in field cages at the International Center of Insect Physiology and Ecology (ICIPE), Nairobi, in 1997 using adult insects collected from a tomato field nearby. Among the four host plants studied, common bean was the most preferred host plant, followed by lablab (*Lablab purpureus* [L.] Sweet), cowpea (*Vigna unguiculata* [L.] Walp.) and okra (*Abelmoschus esculentus* [L.] Moench). There were significant differences between plants with regard to the parameters tested. These results concur with observations in the field during the survey.

Table 2. Species composition (%) of whitefly samples from surveyed regions of Kenya.

Province	Species composition[a]					
	B.t.	T.v.	B.a.	T.r.	A.f.	S.p.
Eastern	61	29	6	0	0	4
Rift Valley	20	80	0	0	0	0
Central	35	60	4	1	0	0
Coast	79	0	21	0	0	0
Western	90	0	7	3	0	0
Nyanza	79	6	5	0	10	0

a. B.t., *Bemisia tabaci*; T.v., *Trialeurodes vaporariorum*; B.a., *Bemisia afer*; T.r., *Trialeurodes ricini*; A.f., *Aleurothrixus floccosus*; S.p., *Siphoninus phillyreae.*

Table 3. Reproductive host plants of whitefly species encountered during surveys in Kenya.

Whitefly species	Crops		Non-cultivated hosts	
	Family	Species	Family	Species
Bemisia tabaci (Gennadius)	Convolvulaceae	*Ipomoea batatas* (L.) Lam.	Acanthaceae	*Asystasia schimperi* T. Anders.
	Cucurbitaceae	*Citrullus lanatus* (Thunb.) Matsum & Nakai	Amaranthaceae	*Achyranthes aspera* L.
		Cucurbita pepo L.		*Achyranthes sicula* L.
		*Momordica char*antia L.	Asteraceae	*Ageratum conyzoides* L.
	Euphorbiaceae	*Manihot esculenta* Crantz		*Aspilia mossambicensis* (Oliv.) Wild
	Leguminosae	*Crotalaria* sp.		*Bidens pilosa* L.
		Lablab purpureus (L.) Sweet		*Emilia discifolia* (Oliv.) C. Jeffrey
		Vigna unguiculata (L.) Walp.		*Galinsoga parviflora* Cav.
		Crotalaria sp.		*Gutenbergia cordifolia* Benth. ex Oliv.
				Tithonia diversifolia (Hemsl.) A. Gray
		Phaseolus vulgaris L.	Commelinaceae	*Commelina benghalensis* L.
	Lamiaceae	*Ocimum basilicum* L.	Convolvulacea	*Ipomoea tricolor* Cav.
	Malvaceae	*Abelmoschus esculentus* (L.) Moench		*Jacquemontia tamnifolia* (L). Griseb.
		Gossypium hirsutum L.	Euphorbiaceae	*Euphorbia heterophylla* L.
	Solanaceae	*Capsicum annuum* L.	Leguminosae	*Rhynchosia hirta* (Andrews) Meikle & Verdc.
		Lycopersicon esculentum Mill.	Lamiaceae	*Leonotis nepetifolia* (L.) R. Br.
		Solanum melongena L.		*Ocimum kilimandsharicum* Guerke
			Malvaceae	*Sida acuta* Burm f.
			Solanaceae	*Datura stramonium* L.
				Nicandra physalodes (L.) Gaertn.
			Verbenaceae	*Lantana camara* L.
			Asteraceae	*Tithonia diversifolia* (Hemsl.) A. Gray
Trialeurodes vaporariorum (Westwood)	Cucurbitaceae	*Cucurbita* spp.	Euphorbiaceae	*Euphorbia heterophylla* L.
		Momordica charantia L.		
	Leguminosae	*Phaseolus vulgaris* L.		
	Malvaceae	*Abelmoschus esculentus* (L.) Moench		
	Solanaceae	*Lycopersicon esculentum* Mill.		
		Solanum melongela L.		
Bemisia afer (Priesner and Hosney)	Convolvulaceae	*Ipomoea batatas* L. Lam.		
	Leguminosae	*Phaseolus vulgaris* L.		
	Malvaceae	*Gossypium hirsutum* L.		
			Asteraceae	*Tithonia diversifolia* (Hemsl.) A. Gray
Trialeurodes ricini (Misra)	Solanaceae	*Lycopersicon esculentum* Mill.	Lamiaceae	*Leonotis nepetifolia* (L.) R. Br.
Aleurothrixus floccosus (Maskell)	Rutaceae	*Citrus* spp.		
Siphoninus phillyreae (Haliday)				Unidentified tree

Samples of 10 plants per field, on average, collected from all surveyed areas, were squashed on nylon membranes and sent to the John Innes Centre, UK, for hybridization. Hybridization signals varied from strong to very weak, probably because of differences in the degree of nucleic acid homology. This could suggest different strains of begomoviruses or different begomoviruses altogether. The signal strength also may have been influenced by the sampling method, because the virus titre may have been low in the particular tissues sampled or at that stage of infection.

At Kibwezi, begomovirus symptoms were observed on sweet pepper (*Capsicum annuum* L.) and a low incidence of WmCSV (about 5%) was recorded on watermelon (*Citrullus lanatus* [Thunb.] Matsum. & Nakai). A variety of mosaic symptoms that need further investigation also were noticed in pepper and watermelon. There were symptoms that suggest that tomato in this region should be tested for potyviruses such as *Potato virus Y* (PVY). Aphid infestation levels were very high at Kibwezi and some of the symptoms observed could be a result of aphid-borne viruses. High incidence and severe symptoms of CMD were observed in Mombasa and Kilifi Districts (Coast Province) and in Kitui District (Eastern Province). The symptoms appeared more severe than those observed in western Kenya. Whether these symptoms are caused by infections of *East African cassava mosaic virus* (EACMV) or are associated with the occurrence of the Ugandan variant needs to be ascertained.

Leaf curl symptoms were found during the survey on non-cultivated host plants. These were *Achyranthes aspera* L., *E. heterophylla* and *Nicandra physalodes* (L.) Gaertn. These plants are therefore likely to act as reservoirs of TYLCV. Severe begomovirus symptoms also were observed on a weed identified as *Gutenbergia cordifolia* Benth. ex Oliv. *E. heterophylla* was found to be a major reproductive host of both *B. tabaci* and *T. vaporariorum* at any site where whitefly infestation occurs and this plant species is present. Therefore, the role of *E. heterophylla* in survival of the disease and the vector outside the crop-growing season needs to be investigated.

Natural enemy species

Forty whitefly parasitoid samples were obtained from the surveys and preliminary identification was carried out. *Encarsia sophia* (Girault and Dodd) was found to be the predominant species, while *Eretmocerus* sp. was encountered in the Central Province. *Encarsia formosa* Gahan was only collected from Mwea in the Central Province. At Nguruman, Rift Valley, the level of parasitization appeared higher than at other survey sites in Kenya.

Some of the 24 predators collected were found feeding on the whitefly pupae. Most were coccinnellids, while a few were spiders and mites but none were identified to species level. *Macrolophus caliginosus* Wagner, bugs known to prey on *T. vaporariorum* in other parts of the world, were collected at several locations in Nguruman (Rift Valley Province), Kibwezi (Eastern province) and Mwea (Central Province).

Geographical range of whitefly and whitefly-transmitted virus infestation

Areas identified as “hot spots” for TYLCV infection include Kibwezi, Kitui, Machakos, Athi River (Eastern Province) and Naivasha (Rift Valley Province). Low incidence of TYLCV symptoms was observed in all other surveyed provinces with the exception of Western and Nyanza Provinces, where no TYLCV symptoms were observed.

B. tabaci was found to be the most common whitefly species in the country (Table 3). *T. vaporariorum* was common in the highlands and was encountered frequently in the Central, Rift Valley and Eastern Provinces. *T. vaporariorum* was not recorded from the Coastal and Western Provinces. The abundance pattern and economic importance of *B. tabaci*/TYLCV differed significantly between provinces. It was found to attain particularly high epidemic incidence (>25% of the tomato with TYLCV symptoms) in Eastern Province (Kibwezi 30%-100%, Kitui 30%-100%, Machakos and Athi River 15%-30%) and in Rift Valley Province (Naivasha 15%-40%), where whiteflies and TYLCV were of great concern to the tomato producers. This suggests that the impact of the *B. tabaci*/TYLCV complex is generally more severe in the dry areas.

In Coast Province, where the weather is hot and humid throughout the year, *B. tabaci* constituted 79% of the collected whitefly specimens. However, only a moderate incidence of TYLCV symptoms (5%-25%) was observed. In Western Province, *B. tabaci* constituted 90% of the collected whitefly specimens and in Nyanza Province, 79% (weather is also hot and humid throughout the year) but no TYLCV symptoms were observed on tomato, other vegetable crops, or weeds, and collected samples were negative when hybridized using a probe to the original Israeli isolate of TYLCV. In Western and Nyanza Provinces, most producers plant tomato as a secondary crop after the main staple cereal crops, maize (*Zea mays* L.) and sorghum (*Sorghum bicolor* [L.] Moench). The *B. tabaci* population at Kibwezi (Eastern Province) is usually very high from December to early March (hot and dry season) but the whiteflies virtually disappear from April to August (long rainy season followed by cold season), despite the presence of the same crops in the irrigated fields throughout the year.

High *T. vaporariorum* populations were observed in Nguruman (Rift Valley Province) where the underside of leaves of tomato, common bean and eggplant (*Solanum melongena* L.) could be found covered with adults and nymphs. In this area, the infestation level only drops during a brief rainy season, around April-May. A similar level of infestation by the same whitefly species was observed in the relatively cooler area of Kihara (Central Province). Direct feeding damage by *T. vaporariorum* was observed in both Central Province (Kihara and Mwea) and Rift Valley Province (Nguruman), where it was the predominant whitefly species.

Since completion of the survey, very high whitefly infestations have been reported in the cut-flower and ornamental plants on export-oriented flower and vegetable farms around Lake Naivasha (Rift Valley Province). The highest TYLCV incidences were observed at altitudes ranging from about 500 to 1000 m altitude (Table 4). *B. tabaci* was the dominant whitefly species up to an altitude of about 1700 m, above which *T. vaporariorum* became dominant.

Increased Socio-economic Understanding

Farmers' assessment of whitefly-related problems

Smallholders dominate vegetable production in Kenya and account for 70% of the total production (Mulandi, 1998). Producers in the survey areas

Table 4. Maximum incidence (% of sampled plants showing disease symptoms) of *Tomato yellow leaf curl virus* (TYLCV) encountered and species composition (%) of whitefly samples collected at different altitudes in Kenya.

Altitude[a] (m)	TYLCV incidence	Whitefly species composition[b]						
		B.t.	T.v.	T.r.	B.a.	S.p.	A.f.	B. spp.
20-270	8	72	6	0	14	8	0	0
520-770	100	81	6	0	13	0	0	0
770-1020	80	33	65	2	0	0	0	0
1020-1270	30	66	25	1	8	0	0	0
1270-1520	15	81	16	0	1	0	0	2
1520-1770	27	77	9	2	5	0	7	0
1770-2020	39	43	53	0	4	0	0	0

a. No survey was conducted in the 270-520 altitude range.
b. B.t., *Bemisia tabaci*; T.v., *Trialeurodes vaporariorum*; T.r., *Trialeurodes ricini*; B.a., *Bemisia afer*; S.p., *Siphoninus phillyreae*; A.f., *Aleurothrixus floccosus*; *B*. spp., *Bemisia* spp.

were surveyed using agreed protocols. Most of the interviewed producers (75%) used their own land, while 13% used rented lands and 12% had other arrangements. The great majority of producers (80%) were men.

Tomato is one of the most important vegetable crops in the country. Virtually all interviewed producers (98%) regarded tomato as their most profitable vegetable crop and 58% of the producers interviewed have cultivated tomato for more than 5 years. Main varieties of tomato grown in the country were Moneymaker and Cal-J, while other varieties include Roma, Marglobe, Petomech, Early Beauty, Mecheast, Bonny Best, Heinz, Floradade, Marmande, Ponderosa and Hotset. However, no tomato variety grown in Kenya was known to be resistant or tolerant to TYLC. Most producers (75%) bought their tomato seed from the local market, while 20% used their own seed and 5% reported buying directly from the seed companies. Other vegetable crops include kale (*Brassica oleracea* L.), common bean, sweet pepper, cabbage (*Brassica oleracea* var. *capitata* L.), eggplant, sweetpotato (*Ipomoea batatas* [L.] Lam.), okra, bitter gourd (*Momordica charantia* L.), melon (*Cucumis melo* L.) and onion (*Allium cepa* L.). Most producers (94%) practised crop rotation.

Fifty-five percent of the interviewed producers listed whiteflies and/or associated virus diseases among their principal pests and diseases and ranked these problems, on average, as their third-most-important problem in tomato. For tomato producers in Kenya, late blight *Phytophthora infestans* (Mont.) de Bary is the main cause of concern as a yield-limiting factor. Other pest and disease problems were early blight (*Alternaria solani* [Ell. and Mart.] Jones and Grout), red spider mites (*Tetranychus urticae* Koch.), bollworms (*Helicoverpa armigera* [Hubner]), leaf miners (*Lyriomyza* spp.), bacterial wilt (*Erwinia tracheiphila* [Smith]), aphids, cutworms (*Spodoptera litura* [Fabricius]), nematodes (Rhabditida: Steinernematidae & Heterorhabditae), end rot (*Godronia cassandrae* f. *vaccinii*), thrips (*Thrips palmi* Karny) and rats (*Rattus* sp.).

Most producers (88%) were able to recognize whiteflies, while only 64% of producers were able to recognize the symptoms of TYLCV and only 1% knew that whiteflies and TYLCV were inter-related. Although only about half of the producers (55%) listed whiteflies and associated viruses among their principal pests and diseases, 79% of interviewed producers believed that whiteflies cause problems in the crops on their farms. Among these producers, 50% attributed the problems to both whiteflies and TYLCV, 47% attributed the problem to whiteflies only, while only 3% mentioned TYLCV alone.

Areas where producers were not able to recognize whiteflies were mainly in Western Province (Funyula, Mokonja and Buhuma), Nyanza Province (South Ugenya and Nyabondo) and Coast Province (Shimba Hills and Kikambala), where whiteflies were scarce. Most producers in these localities also could not recognize TYLCV symptoms and were not aware of its association with the vector. Some thought that TYLCV was either a soil-borne or seed-borne problem, while some confused it with blight.

Most producers who recognized whiteflies and TYLCV symptoms had names for both but in most cases the producers gave non-specific names for whiteflies (e.g., “insects”) and for TYLCV (e.g., “disease”). Most of the names given to the whiteflies literally mean “flies” or “small insects” and local names include e*bichuni* (insect), *keguneta*, *kimbulutwa* (butterfly), *kudni* (insect), *mbuu* (mosquito), *ngaturia*, *okogataa* (mites), *oulolo* (white moulds), *rwagi rweru* (white mosquito), *twihuruta tweru* (small white butterflies), *ume* (aphids), *umuu* (moulds), *vipuvute vidogo* and *obororo* (plant fleas). Names given to the disease problem mean “leaf curling”, “folding” or “stunted plant growth” and local names include *chana matawi* (combing of leaves), *gathuri* (stunted old man), *gikware, gukunja mathangu* (folding of leaves), *kanyaria* (the devastating disease), *kugogonyara* (curly) and *mbaa* (blight).

Estimation of disease incidence and yield losses

Among the surveyed farms, 55% had TYLCV symptoms in their tomato crop. However, very low incidences (1% infection) were found in most parts of Central, Eastern and Coastal Provinces. Incidence of TYLCV symptoms of more than 30% was recorded in 11 out of 94 farms. These were in Kibwezi (3), Kitui (3), Machakos/Athi River (1) and Naivasha (4). High incidence (80%-100%) was only recorded in two farms in Eastern Province, in Kibwezi and Kitui areas. The incidence in Kibwezi resulted in a total loss of the tomato crop. Severe leaf curling plus subsequent yield depression of nearly 100% in sweet pepper was also observed in one experimental plot in Kibwezi. Despite the presence of *B. tabaci* in western Kenya (Western and Nyanza Provinces), no symptoms of TYLCV infection were recorded in this part of the country.

On average, producers’ estimate of the yield loss in tomato production was 30%. According to the survey, 1% reported a total yield loss, 5% reported three-quarter yield loss, 26% reported half yield loss and 50% of the producers reported one-quarter yield loss due to the whitefly/TYLCV complex. The problem was more serious in drier areas where irrigation was practised and this could be because of the presence of TYLCV reservoirs and the virus vector. Eighteen percent of the producers interviewed, mainly from Western Province, thought that their tomato crops did not suffer any yield loss because of the whitefly/TYLCV complex. However, 8% of producers interviewed reported abandoning their tomato crops in at least 1 year because of the problem. These were from Eastern, Rift Valley, Central and Coast Provinces. Half of them reported that the loss occurred in 1997.

Seventy-nine percent of tomato producers believe that they encounter the whitefly/TYLCV complex every year. Almost one-third of the producers (30%) believed that the incidence and severity of whitefly-transmitted viruses, especially in tomato, was exceptionally high in early 1997 before the El Niño phenomenon. Most (89%) also believe that there is a direct relationship between the seasonal weather changes and the whitefly/disease incidence. Seventy-five percent of producers reported that the period from December to March (hot and dry season) was the time when they experience the most serious whitefly/TYLCV problem, while few believed that they have the problem all year round. Producers gave estimation of the costs involved (see below).

Costs estimated by producers in control of whitefly/TYLCV complex per hectare of tomato

US$	% producers
0-49	13
50-99	17
100-199	30
200-299	17
300-400	23

Pesticide use

Almost half of the producers (43%) received advice and recommendations on the use of insecticides from technical advisors, 37% from other producers, neighbours or family members, 10% from pesticides salesmen, while 10% claimed to use chemicals on their own initiative. Most producers (85%) made their own decision on what, when and which insecticides to apply, while only 10% relied on the technical advice they received. Half of the producers (48%) applied insecticides as a preventive measure, 25% applied insecticides when they observed whitefly/TYLCV damage, while 18% applied insecticides routinely according to the calendar. The high level of insecticide usage coupled with prophylactic chemical spraying could easily lead to the whiteflies developing resistance, which would hamper their control.

Because of the lack of virus-resistant tomato cultivars, producers resort to the use of pesticides to combat the whitefly/TYLCV complex. The use of pesticides in most production areas in Kenya has increased, even though it is hazardous and sometimes ineffective and uneconomical. Eighty-six percent of tomato producers used insecticides, mostly pyrethroids and organophosphates, to combat the whitefly problem on their farms. However, 9% of the producers did not practice any sort of control against the problem, while 4% practised crop rotation as a means of combating it. Some producers used a *Bacillus thuringiensis* formulation (Dipel) for control of whiteflies. One producer in Mwea (Central Province) reported using ash, in addition to commercial chemicals, to manage the whitefly/TYLCV complex on his farm. Another producer in Kihara (Central Province) used a home-prepared blend of botanicals and a detergent to manage the whitefly problem but apparently with little success. Chemical control was in many cases directed against blight (i.e., using fungicides). The most commonly used insecticides for control of the whitefly/TYLCV complex in the country were pyrethroids (lambda-cyhalothrin and cypermethrin) and organophosphates (dimethoate and diazinon). Other commonly used insecticides include alpha cypermethrin (pyrethroid), amitraz (amidine), malathion, fenitrothion, and omethoate (organophosphates) and endosulfan (organochlorines). Acaricides such as dicofol, which has little effect on insects (EXTOXNET, 1998), were also commonly applied against whiteflies. The use of fungicides such as metalaxyl, copper sulphate and Mancozeb (ethylene bisdithiocarbamate), in an attempt to combat TYLCV was very common. Almost half the producers (48%) made between one and four insecticide applications per crop season to control the whitefly/TYLCV complex, while only 8% applied nine to ten applications. Most producers in Nyanza and Western Provinces did not apply insecticides or practice any sort of control measure against the whitefly/TYLCV complex.

There was lack of knowledge on proper use of pesticides. Some tomato growers overused chemicals, while others did not spray until symptoms of damage were observed, and subsequent intensive chemical application failed to save the crop. In many cases, producers continued spraying on a crop already severely affected by the virus, using a higher dosage in the hope of curing the plants. Producers were ignorant about the safety period between the last spraying of the crop and date of sale or consumption. Some producers said they did not care about the pre-harvest interval as long as the produce looked good for sale. Some of the local agrochemical suppliers bought large volumes of pesticides and measured out small volumes according to the financial capability of the buyers. The application of inappropriate pesticides and dose rates was common and led to control failure. Chemicals without any labels were usually bought from local dealers.

For the first time in Kenya, information was generated on whitefly resistance to insecticides in selected areas of the country. Assessment of the resistance of *B. tabaci* and *T. vaporariorum* to methomyl (a carbamate), cypermethrin and bifenthrin (pyrethroids) using both glass-vial and leaf-dip bioassays was carried out at Kibwezi, Kitui (Eastern Province), Nguruman (Rift Valley Province) and Mwea and Kihara (Central Province). Generally, *T. vaporariorum* was found to be more resistant to the three insecticides than was *B. tabaci*. Of the three insecticides used in the tests, cypermethrin was the most commonly used in the survey farms and bifenthrin the least. The resistance levels deduced from the analysis showed that both *B. tabaci* and *T. vaporariorum* were more resistant to cypermethrin than to either bifenthrin or methomyl. The results obtained suggest that repeated exposure of whiteflies to specific insecticides could have selected them for resistance to the chemicals. However, this was not a universal conclusion because there were some deviations from the general trend. For instance, a 6.8-fold resistance to bifenthrin was detected at Kihara where the insecticide had reportedly never been used. Whiteflies from Kajiado were the most resistant to cypermethrin, giving a resistance factor value (RF) of 87 in the leaf-dip method, while those from Nairobi were the most resistant to methomyl.

Strengthened Research Capacity

The present work has substantially improved our understanding of the whitefly problem in the major vegetable production areas of Kenya. Quantitative information on whiteflies and natural enemy species diversity and the occurrence of the whitefly-transmitted diseases, mainly TYLCV, as well as the socio-economic understanding of the producers' perception and practices relating to management of the whitefly/TYLCV complex, has provided Kenyan researchers with a solid background for setting a research agenda for further work, some of which may be carried out under Phase 2 of the TWF-IPM Project (see Introduction to this volume). The first, diagnostic, phase of the project also contributed to capacity building through a planning workshop and a mid-term meeting for all participating scientists, training of one M.Sc. thesis student in assessment of insecticide resistance and training of one B.Sc. student in host plant preference studies.

Conclusions

The following areas in Kenya have been identified as hot spots for future research on whiteflies and whitefly-transmitted viruses: Kibwezi, Kitui, Machakos/Athi River and Naivasha. The survey revealed that the prevalent whitefly species in the country are *B. tabaci*, *T. vaporariorum*, *B. afer*, *T. ricini*, *A. floccosus* and *S. phillyreae*. The fact that 55% of the surveyed farms had TYLCV symptoms indicates a potential for whitefly/TYLCV problems in Kenya. The major constraint in producers' knowledge on the whitefly/TYLCV complex was a complete lack of understanding (99% of farmers) of the connection between the disease and the vector.

To minimize the devastating effects of whitefly-transmitted viruses in tomato, sustainable vector- and disease-management options need to be developed, tested and deployed, including the use of resistant and/or tolerant cultivars, as well as cultural and biological control practices. The development of such options needs to be based on, and supported by, appropriate research. In addition, we need to understand the source of whitefly infestations and the reasons behind the striking between-field variability in whitefly population levels that is often observed among fields in close proximity to each other. For example, very heavy whitefly infestation was observed in two adjacent farms at Kihara but not in any of the other nearby farms. The contrast could have been due to the insects' feeding preference, because the two farms had eggplant and squash (both preferred hosts) that were not on the other farms but this possibility would need to be investigated further. We need to understand why there is low or no incidence of TLCV in western Kenya, despite the prevalence of the vector. The potential of local isolates and commercial formulations of entomopathogenic fungi, as well as parasitoids and predators, for control of whiteflies could be evaluated. There is also a need to look at other whitefly-transmitted viral diseases and at the role of weeds as reservoirs of begomoviruses.

There is a need for training of entomologists and virologists in areas of detection, identification and characterization of whitefly-transmitted viruses, whiteflies and their natural enemies, as well as training in epidemiological research methodologies. The continued involvement of scientists from ICIPE and the Asian Vegetable Research and Development Center (AVRDC), who have provided technical support during the first phase of this project, would be helpful. Collaborative work involving the network of regional stations of the Kenya Agricultural Research Institute (KARI) should be extended.

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