8-2011

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Belay, Difabachew K.; Zewdu, Abebe; and Foster, John E., "Ecology and Management of the Woolly Whitefly (Hemiptera: Aleyrodidae), a New Invasive Citrus Pest in Ethiopia" (2011). *Faculty Publications: Department of Entomology*. 636.
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Published in *Journal of Economic Entomology* 104:4 (2011), pp 1329–1338.

doi 10.1603/EC11017

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Submitted 18 January 2011; accepted 7 June 2011.

Ecology and Management of the Woolly Whitefly (Hemiptera: Aleyrodidae), a New Invasive Citrus Pest in Ethiopia

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Abstract

Distribution and importance of woolly whitefly (*Aleurothrixus floccosus*) (Maskell) (Hemiptera: Aleyrodidae), was studied in Ethiopia with an evaluation of treatments against it. Results showed that the pest is distributed in most citrus-growing parts of the country equally infesting all types of citrus crops. Only one pupal parasitoid, *Amitus* sp., was recorded at Melkaoba. During 2006–2007, eight treatments gave better control of woolly whitefly compared with the control: endod (*Phytolacca dodecandra* L'Herit) berry extract, white oil 80%, neem oil, omo detergent soap, band application of gasoline, cyhalothrin (karate) 5% EC, selecron (profenofos) 500 EC, and rimon (novaluron) 10 EC. Treatments were applied on 6–8 yr-old orange trees at Melkaoba and Nazareth. At Melkaoba, application of cyhalothrin, selecron, white oil, and Neem gave better control of woolly whitefly compared with the control. All the treatments resulted in a lower number of ants than the control. Ants disrupt biocontrol agents of honeydew-secreting pests, including woolly whiteflies. Mean infestation score was higher in the control than the rest of the treatments. Similarly, at Nazareth, woolly whitefly numbers were lower recorded on cyhalothrin-treated plants. However, the numbers of eggs were significantly higher in endod extract-sprayed plants than the control. All treatments controlled ants better than the control except endod. Infestation scores were lower on endod- and cyhalothrin-treated plants than the control. Mean number of adult woolly whiteflies and eggs were significantly higher on newly grown leaves than older leaves. In general, the number of live adult woolly whiteflies showed a decreasing trend at both sites after treatment applications compared with the control.

Keywords: *Aleurothrixus floccosus*, citrus, woolly whiteflies, selecron, cyhalothrin

The genus *Citrus*, which includes oranges, lemons, grapefruit, mandarins, and limes, probably originated from southeastern Asia (Swingle 1943, Gmitter and Hu 1990) and has become one of the most important fruit crops. As a good source of vitamin C with high antioxidant potential (Gorinstein et al. 2001), the market for citrus can only increase. Currently, citrus is grown in the subtropical and tropical regions of the world between 40° N and S in >137 countries and six continents, generating nearly US\$105 billion/yr in the world fruit market (Ismail and Zhang 2004). In Ethiopia, citrus is among the major fruit crops grown both for domestic consumption and export. The importance of citrus in the Ethiopian economy is evident from their role as a source of vitamins, raw materials for local industries, and saving and earning of foreign currency through import substitution and export (Seifu 1995). Citrus production is increasing in the country through private and government farms to meet export and local demands (FAO 2004). However, productivity and quality of the produce remains very low mainly due to damage inflicted by insect pests, including woolly whitefly, *Aleurothrixus floccosus* (Maskell) (Hemiptera: Aleyrodidae); fruit flies (Tephritidae); citrus thrips, *Scirtothrips citri* (Moulton); leafminer *Phyllocnistis citrella* (Stainton); and multiple species of scales (Hemiptera).

The woolly whitefly was first recorded in Ethiopia in 2000 from the Wonji area and identified by the International Center of Insect Physiology and Ecology (ICIPE) in 2001 (E. Getu, E. Ahmed, and M. Yesuf; unpublished data). The pest was first recorded from Jamaica and is believed to be native to tropical and subtropical America (Pauloson and Beardsley 1986). The first recorded of woolly whitefly in the mainland United States dates back to 1909 in Florida and arrived in the west coast in the 1960s (DeBach and Rose 1976). The pest has a wide host range and is reported from >50 plant species belonging to 31 families from Hawaii alone; however, citrus is the most preferred host (Pauloson and Beardsley 1986). In the late 1960, the pest spread to Europe and in Africa, it was first recorded in Morocco in 1973 (Abbassi and Onillon 1973) and Kenya in 1990. Currently, it is distributed across much of the African continent and in the late 1980s, its presence was

Fig. 1. A map showing distribution of citrus woolly whitefly in citrus-growing regions of Ethiopia.

reported from a number of eastern and southern African countries, including Uganda, Tanzania, Zambia, Rwanda, Burundi, and in 1994 from Malawi (Legg et al. 2003). Since its introduction into Ethiopia, the pest has reportedly spread through the central Rift Valley areas, such as Nazareth, Debrezeit, Wonji, Melkassa, Meki, and Zeway. Commercial and home growers, as well as the Zeway Prison Citrus Farm, have reported that their citrus plants are dying from a heavy infestation of woolly whitefly, bringing several samples of the pest to the laboratory for advice.

The woolly whitefly gets its name from the white waxy and sugary excretions produced by the nymphs that feed by sucking plant juices from the undersides of leaves. During feeding, some of the sugars crystallize and produce a crust on the underside of the leaves. The excretion, honeydew, can completely cover leaf and fruit surfaces and serves as a substrate for the growth of black sooty mold that

interferes with the photosynthetic activity of the plant, resulting in reduced fruit size and dropping of leaves (Kerns et al. 2009). Moreover, the honeydew is used as food by ants that tend the woolly whiteflies, and the ants interfere with biological control activities against the woolly whiteflies (Gullan 1997). The mutual association between honeydew-secreting hemipterans and ants, in which the hemipterans supply ants with food source and in turn the ants protect them from natural enemies, is reviewed in detail by Way (1963) and Styrsky and Eubanks (2007). Nixon (1951) and Flanders (1951) also reported that honeydew secreting pest populations thrive better when attended by ants, mainly due to provision protection from natural enemies and improved hygiene through removal of contaminating honeydew by the ants. Ants were observed attacking and driving away larvae of Syrphidae and Coccinellidae from honeydew-secreting aphids (Way 1963).

Adult woolly whiteflies are yellowish white, seldom fly, and are found roosting on the underside of fully expanded leaves. Sausage-shaped eggs are laid on the underside of the leaves in a circle, with each egg circle surrounded by a light dusting of waxy scales. A single female can lay up to 200 eggs during her lifetime, and eggs hatch in 4–12 d (Kerns et al. 2009). The woolly whitefly passes through four nymphal stages, with the first instar (crawler) being the only mobile nymphal stage. The second to fourth instars are sedentary and are covered by waxy filaments, honeydew droplets, and cast skins. Different species of natural enemies were introduced into Europe and California as classical biocontrol agents from southern and Central America during the 1970s (DeBach and Rose 1976). However, only two species of parasitoids, *Amitus spiniferus* (Brethes) and *Cales noacki* (Howard), introduced from Mexico and Chile, respectively, established successfully (Miklasiewicz and Walker 1990). In Florida and California, the woolly whitefly is primarily controlled by the parasitoids *Eretmocerus haldemani* (Howard), *Amitus spiniferus* (Brethes), and *Cales noacki* (Howard) (Kerns 2002). The high incidence of woolly whitefly infestation in different African countries after its introduction suggested that indigenous natural enemies are unable to control the pest and classical biological control was implemented in Uganda and Kenya with *C. noacki* (Legg et al. 2003) imported from Europe. The introduction and establishment of *C. noacki* has successfully controlled the woolly whitefly population both in Uganda (Molo 1998) and Kenya

(Legg et al. 2003). Once established, biocontrol agents are effective in controlling woolly whiteflies; however, when the woolly whitefly populations reach economically damaging levels, the use of chemical control is necessary (Kerns 2002). In Ethiopia, where the newly introduced pest has left its natural enemies behind in its native areas, use of chemicals and other alternative options has been necessary to prevent economic damage until effective natural enemies are introduced. This study was conducted to monitor the dynamics of woolly whitefly infestation, levels, and distribution of the pest and to investigate the presence and possible importance of native natural enemies. The other objective was to select effective insecticides and plant extracts for the control of the pest and to recommend management options for citrus growers before the woolly whitefly spreads to uninfected large citrus farms and threatens overall citrus production of the country.

Materials and Methods

Distribution and Importance of Woolly Whitefly and Its Natural Enemies

A survey was conducted from November 2006 to February 2007 in major citrus-growing regions of the country, including the central Rift Valley areas, North Shewa, South Wello, Sidama (Bilate), and South Omo (Arbaminch areas) (Fig. 1; Table 1). A detailed list of sampling sites is indicated in Table 1. The sampling sites include state farms, private farms, and backyards. The number of plants sampled per site varied depending on the number of citrus trees available. Where sufficient trees are available, we examined a maximum of 50 randomly selected plants. In most of the surveyed urban areas, few numbers of different types of citrus (orange, mandarin, lemon, and lime) are grown in private gardens, and we sampled all available trees. Parameters collected during the survey include total number of sampled plants, number of infested plants, total leaf area infestation score per plant based on visual observation of the whole plant, and type of citrus plant. Infestation score for the whole plant was done using a 1–5 scale as described by Kerns and Tony (1998): 1, no whiteflies; 2, <10% leaf area covered; 3, 11–20% covered; 4, 21–50% covered; and 5, >50% covered. Although other citrus-growing areas in the eastern and northern

Table 1. Mean percentage of infested plants and visual leaf area infestation score (1–5 scale) of citrus plants by woolly whitefly in different citrus-growing areas of Ethiopia

Region/zone ^a	Site	Lemon			Lime			Mandarin			Orange		
		No. plants	% infested	score	No. plants	% infested	score	No. plants	% infested	score	No. plants	% infested	score
OR/Arsi	Dhera1	— ^b	—	—	3	33.3	2	5	0.0	0.0	5.0	0.0	0.0
OR/ES	Dhere2	—	—	—	4	100	4	5	100	5.0	10.0	100	3.4
OR/ES	Sodere	—	—	—	4	100	4	8	100	3.3	17.0	100	4.0
OR/ES	Melkassa	7	100	3.2	—	—	—	13	100	3.9	—	—	—
OR/ES	Wonji1	—	—	—	—	—	—	11	100	4.9	29.0	100	5.0
OR/ES	Wonji2	—	—	—	—	—	—	10	100	5.0	8.0	100	4.9
OR/ES	Kuriftu	—	—	—	2	100	5	16	100	4.6	8.0	100	4.5
OR/ES	Nazareth	5	100	5	—	—	—	—	—	—	26.0	100	5.0
OR/ES	Modjo	—	—	—	—	—	—	—	—	—	6.0	83.3	1.8
OR/ES	Debrezeit1	—	—	—	—	—	—	—	—	—	32.0	43.7	1.5
OR/ES	Debrezeit2	—	—	—	—	—	—	6	16.7	1.2	14.0	42.8	1.6
OR/ES	Melkaoba	4	50	1.5	5	40	1.4	—	—	—	26.0	100	2.4
OR/ES	Zeway1	—	—	—	—	—	—	—	—	—	33.0	100	3.7
OR/ES	Zeway2	—	—	—	—	—	—	—	—	—	25.0	100	2.0
OR/ES	Zeway3	—	—	—	9	100	3.2	2	100	4.0	5.0	100	3.4
OR/ES	Meki	—	—	—	—	—	—	14	100	5.0	36.0	100	5.0
AM/NS	Shewarobit	4	100	5	—	—	—	—	—	—	—	—	—
AM/NS	Ataye	—	—	—	—	—	—	—	—	—	30	0.0	1.0
AM/SW	Kemisie	—	—	—	—	—	—	—	—	—	5	100	5.0
SNNP/SD	Bilate	—	—	—	—	—	—	—	—	—	5	100	4.0
SNNP/SO	Arbaminch	8	100	5	—	—	—	—	—	—	—	—	—
OR/ES	Merit (UA)	—	—	—	—	—	—	—	—	—	30	100	4.0
OR/Arsi	Tibilla (UA)	—	—	—	—	—	—	—	—	—	30	0.0	1.0
AA/AA	AA	—	—	—	—	—	—	—	—	—	5	100	4.0

a. OR, Oromia; ES, East Shewa; AM, Amhara; NS, North Shewa; SW, South Wello; SNNP, Southern Nations, Nationalities and People; SD, Sidama; SO, South Omo; UA, Upper Awash; AA, Addis Ababa.

b. — : data not available.

parts of Ethiopia are not covered in the survey due to time and resource limitations, there are no reports of the woolly whitefly problem either from the growers or other research stations in the regions.

To recover natural enemies, infested twigs were covered and tied with cloth bags at Melkaoba, Nazareth, and Melkassa, locations that were suitable for frequent visits. Every 15 d, the twig was shaken, and all insects in the bag were transferred into another container. The process was then repeated to observe further emergence of natural enemies. New twigs also were covered to detect parasitism that may have occurred in the meantime. Leaf sampling for parasitoid recovery was done three times and from each site 10 infested plants were

sampled and a single infested twig per plant was collected in paper bags or covered in the field from 10 infested plants. The leaf samples collected in paper bags were checked for parasitoid emergence after 4 wk of collection. Insects collected from the different collection methods were transferred to 70% ethyl alcohol and identified locally. In addition, from all surveyed areas infested leaves (twigs) were collected and kept in paper bags under laboratory conditions to observe the emergence of parasitoids. Woolly whitefly samples found in the survey areas were compared with the woolly whitefly samples that we collected in 2001 and identified by ICIPE to confirm the species identity. Parasitoid identification support was provided by Dr. Paolo A. Pedata (Institute for Plant Protection National Research Council, Portici, Italy), who came to our laboratory for another collaborative project on whitefly parasitoids survey in Ethiopia.

Management of Woolly Whitefly

Evaluation of different treatments, including commercial insecticides and plant extracts, was carried out at Nazareth and Melkaoba during 2006–2007. The amount of water used to spray one citrus plant was calibrated to be 4 liters. The treatments were as follows: 1) endod (*Phytolacca dodecandra* L'Herit) berries extract at a rate of 10 g of berries powder per 1 liter of water; 2) white oil 80% (petroleum oil), 100 ml per tree (Upper Awash Agroindustry); 3) neem oil azadirachtin 1% (UNO Naturals and Greens PVT Ltd., Tamil Nadu, India), 3 ml per tree; 4) omo detergent soap, 10 ml per tree (obtained from a local grocery store); 5) band application of gasoline at 10-cm width at the bottom of the tree; 6) cyhalothrin 5% EC (Syngenta, Addis Ababa, Ethiopia), 2 ml per tree; 7) Selecron 500 EC (Syngenta), 3 ml per tree; 8) Rimon 10 EC (Chemtex, Addis Ababa, Ethiopia), 2.4 ml per tree; and 9) control (untreated).

On both sites, the experiment was conducted on 6–8-yr-old navel orange trees. The grove at Nazareth is owned by Adama #4 Elementary School, and the grove at Melkaoba is owned by the East Shoa Zone Bureau of Agriculture and Rural Development. The grove at Melkaoba was well maintained in terms of irrigation, weed control, and fertilization compared with the grove at Nazareth. Moreover, the infestation at Nazareth seems older than that at Melkaoba, as evident from coverage of most of the leaf areas with sooty mold, skin casts, and woolly filaments of the woolly whiteflies.

Endod berries were obtained from Aklilu Phytopathology Institute (Addis Ababa, Ethiopia). The berries were ground with a mortar and pestle, and the powder was soaked overnight in water before spraying. Neem oil and other insecticides were obtained from pesticide companies, and we obtained the gasoline from local gas station (Shell Ethiopia). Each treatment was replicated three times in a randomized complete block design. To get uniform trees for the experiment, a single tree was used as one replication. Two unsprayed trees were left as a buffer between treatments within a row to reduce spray drift and the blocks (rows) were spaced 8 m apart. Spraying of chemicals, oils, and detergents was made using a knapsack sprayer over the whole tree, whereas gasoline was applied with a brush only on the trunk, near the soil surface in a 10-cm width without leaving any path for the ants to deter them from climbing on the trees. Ants usually form a mutual association between honeydew-producing pests such as the woolly whitefly (Beattie 1985). The ants disrupt or kill parasitoids and predators of honey-secreting pests to protect their food source (Gullan 1997). To evaluate efficacy, treatments were only applied on plants with a sufficient level of infestation (5–10 adults per five leaves and visual observation of the overall infestation). Trees were sprayed three times at 10-d intervals at both sites. Data were collected six times, one sample before spray, one sample 1 wk after each spray, and two additional samples after the last spray at weekly intervals following the method described by Kerns (2002). Five new fully expanded leaves and five hardened leaves per plant were randomly sampled and transported to the laboratory where numbers of both adult whiteflies and ants were recorded. Each sample was kept in a separate tightly closed plastic bag. Numbers of woolly whitefly eggs and nymphs were counted by cutting leaf samples of 1 in.2 from the middle of each leaf bisecting the midvein. Eggs and nymphal stages were counted under a binocular microscope. Because we felt that single leaf sampling alone may not be sufficient to obtain an accurate estimate of adults as they may fly when disturbed during cutting of leaves, we additionally sampled two twigs per tree by covering the twigs with plastic bags, with minimum disturbance, and then cut them with pruning shears. Numbers of adult woolly whiteflies, as well as any ants, were then recorded. Proportion of leaf area infested for the whole plant was scored based on visual observation of 1–5 scale similar to the survey described above.

Statistical Analyses

Analysis of variance (ANOVA) was performed using the Proc GLM procedure of SAS (SAS Institute 1999). Whenever ANOVA showed significant differences between treatments, means were separated using the Student–Newman–Keuls test (SNK). Percentage and count data were transformed using arcsine and square root transformations, respectively, before being subjected to statistical analysis. When treatments showed significant interaction with locations for a given parameter, data were analyzed for each location separately. But, in the absence of significant interaction between parameters ($P > 0.05$), pooled data were used. The significance level was set at $P = 0.05$.

Results

Distribution and Importance Woolly Whitefly and Its Natural Enemies

The survey results showed that the pest is distributed in central Rift Valley areas of East Shoa (Melkassa, Dhera, Upper Awash, Zeway, Meki, Nazareth, Modjo, and Debreziet), Addis Ababa, Bilate (southern Ethiopia), Shewrobit, Ataye, and Kemisie (northern Ethiopia) (Fig. 1; Table 1). On infested citrus plantations or gardens, percentages of infested plants vary from 16.7 to 100% across the different sampling sites (Table 1). The overall leaf area infestation score, which was covered by the pest and its damage symptoms (waxy filaments and sooty mold), also was generally high both across crops and locations (Table 1). When we consider the overall infestation, the pest equally attacks all kinds of citrus plants sampled, and there was no significant difference both in terms of mean percentage of infested plants (Fig. 2.) and leaf area infestation per plant (Fig. 3). At upper Awash, which is the largest citrus farm in the country, infestations were only seen at Tibilla, in the older plantation, and the woolly whitefly was not yet distributed to other farms or the young plantation of the Tibilla farm. At Shewarobit, the pest has not yet been recorded on the Prisoners' Citrus Farm, the largest farm in the area, although woolly whitefly has infested nearby lemon plants in private gardens and at hotels. With regard to natural enemies, only one pupal parasitoid, *Amitus* sp., was recorded from the samples collected at Melkaoba.

Fig. 2. Overall mean percentage of infested citrus crops by citrus woolly whitefly in different citrus-growing areas of Ethiopia. No significant difference among crops in terms of percentage of infested plants ($P = 0.05$; SNK).

Fig. 3. Overall mean infestation score of different citrus crops by citrus woolly whitefly in different citrus-growing areas of Ethiopia during 2007. No significant difference among crops in infestation scores ($P = 0.05$; SNK).

Management of Woolly Whitefly

Significant differences were observed at Melkaoba between woolly whitefly treatments from the data collected on five leaves per plant in terms of adult woolly whitefly ($F = 3.26$; $df = 8, 254$; $P < 0.0001$), number of eggs ($F = 3.54$, $df = 8, 254$; $P < 0.0001$), and number of ants ($F = 8.24$; $df = 8, 254$; $P < 0.0001$). The lowest numbers of woolly whiteflies were recorded in the cyhalothrin- and white oil-treated trees compared with the control (Table 2). Similarly orange trees sprayed with selecron, cyhalothrin, and white oil resulted in

Table 2. Mean $\pm$ SE of adult woolly whiteflies and ants per five leaves, and number of eggs and nymphs per 5-in.2 on Navel orange trees sprayed with different treatments at Melkaoba, Ethiopia

<i>Treatment</i>	<i>No. adults</i>	<i>No. eggs</i>	<i>No. live nymphs</i>	<i>No. dead nymphs^a</i>	<i>No. ants</i>
Control	6.2 $\pm$ 1.1ab	70.1 $\pm$ 20.6abc	15.1 $\pm$ 2.8a	0.5 $\pm$ 0.2	6.1 $\pm$ 1.5a
Endod	4.6 $\pm$ 1.1abc	95.7 $\pm$ 17.1ab	10.9 $\pm$ 2.8abc	1.0 $\pm$ 0.4	2.9 $\pm$ 1.1bcd
Gasoline	4.2 $\pm$ 1.4abc	50.3 $\pm$ 12.4abc	9.7 $\pm$ 3.3bc	0.6 $\pm$ 0.3	1.4 $\pm$ 0.6cd
Neem	3.4 $\pm$ 0.7bc	50.1 $\pm$ 11.1abc	13.9 $\pm$ 4.4ab	1.1 $\pm$ 0.4	4.2 $\pm$ 1.8b
Rimon	9.5 $\pm$ 2.3a	102.1 $\pm$ 18.5a	7.7 $\pm$ 1.9abc	0.4 $\pm$ 0.2	0.9 $\pm$ 0.4cd
Selecron	3.9 $\pm$ 1.6bc	47.5 $\pm$ 9.9abc	5.1 $\pm$ 1.4 c	1.0 $\pm$ 0.9	0.2 $\pm$ 0.1d
White oil	1.7 $\pm$ 0.8c	25.9 $\pm$ 6.8c	2.0 $\pm$ 0.8c	0.4 $\pm$ 0.2	2.4 $\pm$ 1.0bcd
Cyhalothrin	2.5 $\pm$ 0.7bc	40.3 $\pm$ 9.5bc	4.4 $\pm$ 1.4c	1.3 $\pm$ 1.1	0.2 $\pm$ 0.1d
Soap	5.4 $\pm$ 1.6abc	64.2 $\pm$ 12.2abc	14.5 $\pm$ 3.3ab	0.8 $\pm$ 0.3	3.3 $\pm$ 1.2bc

Means within a column followed by the same letter are not significantly different from each other ($P = 0.05$; SNK).

a. No values within the column are significantly different from each other.

lower numbers of live nymphs. The band application of gasoline also resulted in lower numbers of live nymphs than the control (Table 2). Numbers of ants were significantly higher in the control than the rest of the treatments. The lowest number of ants was recorded in the cyhalothrin- and selecron-treated trees. No statistically significant difference was observed between treatments in terms of dead nymphs ($F = 0.48$; $df = 8, 254$; $P = 0.8770$). From visual assessment of overall infestation, we found a significant range of differences among treatments in terms of leaf area infestation score ($F = 7.03$; $df = 8, 145$; $P < 0.0001$). Leaf infestation score was higher in the control treatments compared with the rest of the treatments, except white oil and soap (Fig. 4). Treatments at Melkaoba also varied significantly in terms of the number of adult woolly whiteflies ($F = 6.11$; $df = 8, 202$; $P < 0.0001$) versus number of ants ($F = 8.37$; $df = 8, 202$; $P < 0.0001$), based on data collected from two twigs per plant that were sampled randomly. The results were similar to that of the single leaf sampling, from which lower numbers of woolly whiteflies and ants were recorded from plants sprayed with selecron, cyhalothrin, or white oil (Table 3). Numbers of adult woolly whiteflies and ants per leaf also varied among treatments, showing a similar trend to that of woolly whiteflies and ants per twigs. The highest and lowest numbers of woolly whiteflies and ants were recorded from the cyhalothrin and control treatments, respectively (Table 3). The number of live woolly whitefly adults showed a decreasing trend after the first spray and subsequent sampling periods compared with the prespray population (Fig. 5).

Table 3. Mean $\pm$ SE of adult woolly whiteflies and ants on Navel orange trees sprayed with different treatments at Melkaoba, Ethiopia, based on sampling of two twigs per plant

Treatment	Leaves /2 twigs	Woolly whiteflies /2 twigs	Ants /2 twigs	Woolly whiteflies /leaf	Ants /leaf
Control	21.8 $\pm$ 0.9ab	31.2 $\pm$ 6.1ab	31.2 $\pm$ 9.5a	1.2 $\pm$ 0.2ab	1.3 $\pm$ 0.4a
Endod	24.1 $\pm$ 1.3a	23.3 $\pm$ 8.1abc	15.3 $\pm$ 5.2ab	1.3 $\pm$ 0.4ab	0.7 $\pm$ 0.2ab
Gasoline	23.5 $\pm$ 1.1ab	41.0 $\pm$ 10.2a	1.3 $\pm$ 0.6bc	1.8 $\pm$ 0.4a	0.1 $\pm$ 0.0b
Neem	19.5 $\pm$ 0.7b	33.3 $\pm$ 7.9ab	25.1 $\pm$ 5.6a	1.8 $\pm$ 0.4a	1.3 $\pm$ 0.3a
Rimon	24.3 $\pm$ 1.0a	12.6 $\pm$ 2.4bcd	6.8 $\pm$ 2.0bc	0.5 $\pm$ 0.1b	0.3 $\pm$ 0.1b
Selecron	24.6 $\pm$ 1.8a	8.8 $\pm$ 2.8cd	0.5 $\pm$ 0.2c	0.4 $\pm$ 0.1b	0.0 $\pm$ 0.0b
White oil	22.7 $\pm$ 0.7ab	6.5 $\pm$ 1.4cd	1.8 $\pm$ 0.5bc	0.3 $\pm$ 0.0b	0.1 $\pm$ 0.0b
Cyhalothrin	24.5 $\pm$ 1.3a	6.1 $\pm$ 2.2d	0.2 $\pm$ 0.1c	0.2 $\pm$ 0.1b	0.0 $\pm$ 0.0b
Soap	22.3 $\pm$ 1.1ab	25.9 $\pm$ 9.0abcd	10.9 $\pm$ 5.0bc	1.2 $\pm$ 0.4ab	0.5 $\pm$ 0.2b

Means within a column followed by the same letter are not significantly different from each other ($P = 0.05$; SNK).

Fig. 4. Mean leaf infestation score of orange trees by woolly whitefly at Melkaoba, Ethiopia. Bars followed by the same letter are not significantly different from each other ($P = 0.05$; SNK). **Fig. 5.** Mean number of live adult woolly whiteflies (WWF) at prespray and post-spray samplings at Melkaoba, Ethiopia.

Results of the experiment conducted at Nazareth showed significant differences among treatments in terms of adult woolly whitefly numbers ($F = 4.52$; $df = 8, 284$; $P < 0.0001$), eggs ($F = 3.95$; $df = 8, 284$; $P = 0.0002$), and ants ($F = 11.41$; $df = 8, 284$; $P < 0.0001$). Similar to that of Melkaoba, lower numbers of woolly whiteflies were recorded from cyhalothrin and selecron. The number of eggs was significantly higher on detergent soap-sprayed plants compared with the rest of the treatments, with no significant difference in egg numbers among the rest of the treatments (Table 4). With the exception of endod extract, all treatments suppressed the ant population on the plants compared with the control. The highest and lowest numbers of ants per five leaves were recorded from the check and selecron- or cyhalothrin-sprayed plants, respectively (Table 4). No significant difference among treatments was observed with regard to both live and dead nymphs.

At Nazareth, only endod- and cyhalothrin-sprayed plants showed lower leaf infestation scores compared with the control (Fig. 6). From the data collected on two twigs per plant, significant differences were found among treatments in terms of numbers of woolly whiteflies and ant numbers per two twigs. All the treatments except gasoline and Neem resulted in lower numbers of woolly whiteflies per two twigs than the control, and the data converted to single leaf basis also showed a similar trend (Table 5). Similar to that of Melkaoba, number of live woolly whiteflies showed a decreasing trend after treatment applications compared with the control (Fig. 7).

Table 4. Mean $\pm$ SE adult woolly whiteflies and ants per five leaves, and numbers of eggs and nymphs per 5 in.2 on Navel orange trees sprayed with different treatments at Nazareth, Ethiopia

<i>Treatment</i>	<i>No. adults</i>	<i>No. eggs</i>	<i>No. live nymphs^a</i>	<i>No. dead nymphs^a</i>	<i>No. ants</i>
Control	5.0 $\pm$ 1.1ab	2.5 $\pm$ 1.9b	19.1 $\pm$ 4.2	6.6 $\pm$ 1.6	10.9 $\pm$ 2.2a
Endod	4.6 $\pm$ 1.5abc	0.0 $\pm$ 0.0b	15.8 $\pm$ 4.5	9.2 $\pm$ 2.8	7.2 $\pm$ 1.6ab
Gasoline	3.7 $\pm$ 1.0abc	1.7 $\pm$ 1.4b	12.7 $\pm$ 3.5	16.4 $\pm$ 5.7	5.0 $\pm$ 1.7bc
Neem	7.9 $\pm$ 2.1a	4.3 $\pm$ 2.0b	18.3 $\pm$ 5.7	6.2 $\pm$ 1.7	2.5 $\pm$ 0.7dc
Rimon	4.9 $\pm$ 1.6abc	0.3 $\pm$ 0.3b	20.9 $\pm$ 4.8	13.9 $\pm$ 3.7	5.4 $\pm$ 1.4bc
Selecron	1.0 $\pm$ 0.4c	1.3 $\pm$ 0.9b	9.4 $\pm$ 3.3	7.1 $\pm$ 1.6	0.2 $\pm$ 0.1d
White oil	2.0 $\pm$ 0.7bc	1.4 $\pm$ 1.0b	11.1 $\pm$ 3.6	5.7 $\pm$ 1.2	0.7 $\pm$ 0.3d
Cyhalothrin	1.2 $\pm$ 0.5c	0.0 $\pm$ 0.0b	12.9 $\pm$ 4.0	6.8 $\pm$ 1.2	0.2 $\pm$ 0.1d
Soap	2.8 $\pm$ 0.8abc	12.4 $\pm$ 4.6a	17.1 $\pm$ 3.9	12.3 $\pm$ 3.6	2.6 $\pm$ 0.9dc

Means within a column followed by the same letter are not significantly different from each other ($P = 0.05$; SNK).

a. No values within the column are significantly different from each other.

Table 5. Mean $\pm$ SE of adult woolly whiteflies and ants present in Navel orange trees sprayed with different treatments at Melkaoba, Ethiopia, based on sampling of two twigs per plant

Treatment	Leaves /2 twig ^{ns}	Woolly whiteflies /2 twigs	Ants /2 twigs	Woolly whiteflies /leaf	Ants /leaf
Control	20.0 $\pm$ 0.9	6.0 $\pm$ 2.1b	142.0 $\pm$ 18.9a	0.3 $\pm$ 0.1ab	7.1 $\pm$ 0.9a
Endod	21.6 $\pm$ 1.4	1.0 $\pm$ 0.6c	109.3 $\pm$ 55.8ab	0.1 $\pm$ 0.0c	5.1 $\pm$ 2.6ab
Gasoline	24.5 $\pm$ 2.5	9.5 $\pm$ 1.4a	65.5 $\pm$ 7.7bc	0.4 $\pm$ 0.1a	2.6 $\pm$ 0.0bc
Neem	23.6 $\pm$ 0.9	3.0 $\pm$ 0.9bc	38.0 $\pm$ 6.3bcd	0.1 $\pm$ 0.0bc	1.6 $\pm$ 0.3c
Rimon	21.5 $\pm$ 2.9	1.0 $\pm$ 0.3c	53.0 $\pm$ 18.7bcd	0.1 $\pm$ 0.0c	2.0 $\pm$ 0.5c
Selecron	20.3 $\pm$ 2.0	0.0 $\pm$ 0.0c	0.0 $\pm$ 0.0d	0.0 $\pm$ 0.0c	0.0 $\pm$ 0.0c
White oil	21.6 $\pm$ 0.4	0.6 $\pm$ 0.4c	0.0 $\pm$ 0.0d	0.0 $\pm$ 0.0c	0.0 $\pm$ 0.0c
Cyhalothrin	19.3 $\pm$ 2.3	1.3 $\pm$ 0.8c	0.0 $\pm$ 0.0 d	0.1 $\pm$ 0.0c	0.0 $\pm$ 0.0c
Soap	26.3 $\pm$ 0.4	3.6 $\pm$ 1.7bc	20.0 $\pm$ 7.1cd	0.1 $\pm$ 0.0bc	0.7 $\pm$ 0.2c

Means within a column followed by the same letter are not significantly different from each other ($P = 0.05$; SNK).

Fig. 6. Mean leaf infestation score of orange trees by woolly whitefly at Nazareth, Ethiopia. Bars followed by the same letter are not significantly different from each other ($P = 0.05$; SNK). **Fig. 7.** Mean number of live adult woolly whiteflies (WWF) at prespray and post-spray samplings at Nazareth, Ethiopia.

Because leaf stage showed significant influence on the number of adult woolly whiteflies ($F = 57.29$; $df = 1, 518$; $P < 0.0001$) and number of eggs in all locations ($F = 43.83$; $df = 1, 518$; $P < 0.0001$), but no type of leaf by location interaction, data of the two sites was pooled. Results indicate that the number of woolly whiteflies are significantly higher on new (young) leaves than old (hardened) leaves, except in the selecron- and cyhalothrin-sprayed trees (Fig. 8). Similarly, higher numbers of eggs were recorded in new leaves than old leaves for most of the treatments (Fig. 9).

Fig. 8. Mean number of adult woolly whiteflies (WWF) on new and old leaves of Navel orange trees sprayed with different insecticidal materials and plant extracts in 2006 and 2007. Asterisk (*) indicates significant difference between mean values of new and old leaves.

Fig. 9. Mean numbers of eggs on new and old leaves of Navel orange trees sprayed with different insecticidal materials and plant extracts in 2006 and 2007. Asterisk (*) indicates significant difference between mean values of new and old leaves.

Discussion

From the survey results, our study suggests that the woolly whitefly is more widespread in urban areas than rural areas on small gardens and backyards, with the level of infestation being very high in urban areas in which we have recorded up to 100% infested citrus plants and 95% leaf area infestation (score of 5) per plant. Corroborating our findings, survey results by Ulusoy et al. (2003) showed that woolly whitefly infestation and *C. noacki* had been found on citrus, mostly in urban areas of the eastern Mediterranean and Turkey. Although the pest did not infest most of the large citrus farms in Ethiopia, it is recorded from Tibilla, a large citrus farm located in a rural area. The survey results indicated that the pest is spreading to parts of Ethiopia not previously reported by growers and extension agents. The pest was reported previously as a problem only from Nazareth and Wonji areas. Also, D.B. did not observe the woolly whitefly infestation in 2004–2005 while conducting a countrywide survey on fruit flies, including areas surveyed in the current study where woolly whitefly was recorded. Moreover, it seems that the pest is spreading faster in the urban areas than in rural areas. This may be caused by movement of goods and people from town to town, which has aided the movement of the pest. Hence, efforts such as inspections and sanitation should be made to prevent spreading of the pest.

During the survey, no parasitoid was recorded affecting the woolly whitefly except one specimen of *Amitus* sp. at Melkaoba. Katsouranos et al. (1997) also reported that no indigenous parasitoid was ever found parasitizing *A. floccosus* after its introduction in Greece in 1991. They were able to control it within 1 yr, however, with a newly introduced parasitoid, *C. noacki*, released in 1993. Other reports also indicated that the introduction of a hymenopterous parasitoid *C. noacki* into France, Spain, Portugal, and Italy for classical biological control has successfully reduced the woolly whitefly populations (Carrero 1979, Silva Magalhaes 1979). Ulusoy et al. (2003) also reported that the inoculative release of *C. noacki* in Turkey controlled woolly whitefly within a year. Hence, the importation and release of natural enemies such as *C. noacki* in Ethiopia could be more effective to control the woolly whitefly.

Although woolly whitefly may be effectively controlled with natural enemies, when populations of woolly whiteflies increase to high levels, the growers must apply insecticide sprays to avoid catastrophic damage (Garcia-Mari and Soto 2001). In Ethiopia, the pest is newly introduced and is spreading to most citrus-growing areas and indigenous natural enemies are not effective against it. Thus, use of insecticides or plant extracts (botanicals) is recommended as a short term remedy. The results for the Melkaoba experiment indicate that the woolly whitefly population was reduced in selecron-, white oil-, and cyhalothrin-treated trees compared with the control, indicating that those treatments can be used to control the pest until classical biological control is implemented. All treatments also controlled ants compared with the control. Ant control should be a component in honeydew-secreting pest management programs, especially if biological control is in place. Because of the mutual association between honeydew producing pests and ants (Beattie 1985), ants will disrupt or kill the parasitoids and predators of the honeydew-secreting pests such as the woolly whitefly to protect their food source (Gullan 1997). Although we did not record a satisfactory biocontrol agent, it has been reported that several species of parasitoids and predators of honeydew-secreting pests were more effective when ants were controlled (Moreno et al. 1987, Itioka and Inoue 1996).

As at Melkaoba, at Nazareth, selecron and cyhalothrin were more effective in lowering the woolly whitefly population compared with the control. However, the numbers of ants were higher on endod berry extract-sprayed plants than other treatments. In general, results from the two sampling methods used, i.e., five leaves per plant and two twigs per plant showed a similar trend in efficacy of treatments, indicating that the single leaf method of sampling described by Kerns (2002) is appropriate for woolly whitefly sampling. Comparison of the abundance of adult woolly whiteflies and eggs between new and old leaves indicates that, in most of the cases, numbers of woolly whitefly and their eggs were more abundant on new leaves than old ones. This suggests that frequent treatment application may be necessary to prevent infestations on newly growing shoots (leaves). On the contrary, Fasulo and Brooks (2009) reported that unlike other whitefly species, woolly whitefly eggs are laid on older leaves rather than new leaves.

In summary, although the woolly whitefly has not yet spread to the large citrus farms, it is already present in the major citrus-growing parts of Ethiopia where it occurs at a very high level of infestation and attacks all types of citrus crops. The current data shows that the pest occurs at a wide range of altitudes in Ethiopia, from 1,407 m at Melkaoba to 1,916 m at Debreziet, indicating the potential of the pest to spread to all citrus-growing areas. So far, no natural enemy has been found attacking the pest in Ethiopia except one specimen of *Amitus* sp. This suggests that there are no adequate indigenous parasitoids to control this newly introduced pest population. Previous studies in other African countries also showed that native natural enemies were not able to control the woolly whitefly population, and successful biological control programs were implemented through importation of exotic parasitoids such as *C. noacki* (Molo 1998, Legg et al. 2003). Hence, attempts should be made to introduce and release exotic parasitoids like *C. noacki* that have shown satisfactory results as a classical biocontrol agent against woolly whitefly in other countries. Because the woolly whitefly population is found to be higher on newer than older leaves, control strategies that involve foliar spray should cover the entire plant, especially the new leaves. At this stage, we recommend foliar application of selegon, cyhalothrin, neem oil, or rimon. However, if possible, we encourage growers to use neem oil and rimon together with a band application of gasoline at the base to reduce nontarget, broad-spectrum effects of cyhalothrin and selegon on natural enemies of other citrus pests such as scales, which are also significant citrus pests in Ethiopia.

Acknowledgments — We are grateful to Adama #4 Elementary School and East Shoa Zone Bureau of Agriculture and Rural Development for allowing us to use their citrus orchards. The technical support and cooperation of Tadele Aytenfisu (Melkassa Research Center) during our survey study is duly acknowledged. We are also grateful to Melkassa Research Center entomology staff for technical and labor support during the study. We acknowledge ICIPE for woolly whitefly identification. We are also grateful to Paolo A. Pedata for parasitoid identification. Finally, we thank Melkassa Agricultural Research Center for the financial support and provision of facilities for the study.

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