INTERSTATE PEST CONTROL COMPACT

FINAL REPORT

"Evaluation And Development Of Tactics To Reduce or Eliminate Infection of Transplants By *Tomato Yellow Leaf Curl Virus* And Other Whitefly-Transmitted Geminiviruses"

J. E. Polston and D. J. Schuster
University of Florida, Gulf Coast Research and Educ. Ctr.

Funding Period: November 1999 to May 2001

Executive Summary
We found several new possibilities for the protection of transplants from transmission of TYLCV. We demonstrated that a Novartis product, Fulfill, provided very good protection against virus-carrying whiteflies. A single application gave 4 to 7 days of protection from large numbers of whiteflies reared on TYLCV infected plants. We developed a method for measuring the ability of a compound to repel whiteflies, and have used it to evaluate 30 compounds. Several were found to have repellency in the bioassay. Several of the products that tested as repellent in the bioassay were tested in the greenhouse and found to reduce whitefly oviposition and to interfere with begomovirus transmission. Some of these show promise as possible new approaches to protecting transplants from virus transmission. We have tested several other products for their ability to increase plant resistance to infection, or for their ability to kill whiteflies before transmission can occur. Actara, a Novartis product, was found to interfere with virus transmission but many other products that we tested did not. We established a technique to measure transmitted and reflected UV light and used it to measure UV light in transplant houses. This work demonstrated that most of the plastics that growers are using filter out some of the UV light, and that UV light which enters from the sides of open-sided planthouses only penetrates about 4 feet into planthouses. Due to the harmful effect of the absence of UV light on transplants, this approach might be best pursued in planthouses in which fruit is produced. We have found several new plant hosts of TYLCV that are produced as transplants in Florida. In summary, this project has identified at least one new management approach (Fulfill) that can be used immediately to reduce the number of virus-infected transplants, and several other approaches that need further study for development into future management practices.

INTRODUCTION

Whiteflies transmit an ever increasing number of plant viruses, one of which, tomato yellow leaf curl virus, is a known pathogen of several important crops in Florida and the southern U.S. In the 1990's TYLCV appeared in the Western Hemisphere and spread to new countries both in the Caribbean and in the Mediterranean, at least in part through the distribution of infected transplants. Beyond a few insecticides transplant producers have few means by which to manage whiteflies before they can transmit viruses to the developing transplants.

The goal of these studies is to discover new methods by which whiteflies can be discouraged from transmitting TYLCV to susceptible transplants. In order to be implemented these methods will have to be cost effective and consistent with current practices. In addition some of these approaches may be useful for management of TYLCV in the field thereby reducing the number of virus-carrying whiteflies that pass through greenhouses and screenhouses. We expect that a combination of several of these tactics may prove to be the most effective in reducing or essentially eliminating the incidence of TYLCV in transplants.

We began work on the objectives in November 1999. We hired three people to work on this project, one full time and two half-time employees. A visiting scholar (Dr. L. Ortega) participated in the repellency studies described in Objective 1 from January through March 2000. The following is a summary of the results obtained.

We invited a second scholar, Dr. Moshe Lapidot, to Florida to talk on his work with UV-absorbing plastics. He presented a seminar in Gainesville on 6 November entitled "UV-absorbing Plastics for Use in Whitefly Management". He also presented a paper on the same topic at the 17^{th} National Tomato Disease Workshop in W. Palm Beach, FL on 9 November.

Objective 1. Identify approaches that interfere with whitefly feeding behavior and reduce transmission of TYLCV.

AND

Objective 2. Evaluate new approaches for reducing whitefly movement into production houses.

A. UV ABSORBING SCREENS AND PLASTICS

Evaluation of Florida Planthouses for Presence of UV light. UV light between the wavelengths of 350 and 425 nm has been found recently to be critical to whitefly movement and feeding behavior. In order to study this in more depth and use this in whitefly/virus management, we used a UV/VIS portable spectrophotometer and computer to measure the amount of UV that passes through or is reflected by various agricultural plastics and screens. We evaluated the presence of UV in a research planthouse to determine how UV light between the wavelengths of 350 and 425 nm is distributed in various types of greenhouses. We used this information to develop a sampling design that was used to measure the amount of UV light that exists in commercial planthouses.

Our survey of commercial planthouses revealed that UV light from the outside penetrated only about 4 ft. into open-sided planthouses. Polycarbonate/fiberglass reduced UV light 75-85% (compared to outside conditions). Polyethylene plastic reduced UV light by 55- 60%. Age of either material did not have any significant impact on how much UV light was transmitted. Both materials did not reduce UV light sufficiently to impair whitefly movement. We learned from Dr. Moshe Lapidot that UV-absorbing plastics cannot be used with transplant production because the absence of UV light causes the transplants to become etiolated. However, these plastics would be very helpful to the tomato fruit producers in Florida who are having a very difficult time managing incidences of TYLCV-infected plants. These plastics would not interfere with the growth of tomato plants for fruit production.

B. CHEMICAL REPELLENTS

Development of a Laboratory Bioassay to Measure Repellency to Whiteflies. A laboratory bioassay method was developed to evaluate and compare various commercial products and chemical compounds for repellency to silverleaf whitefly adults. Bioassay chambers were constructed from plexiglass cylinders with organdy-covered bottoms for ventilation. Starved whitefly adults were released into the chambers where they had access to either treated or non-treated tomato leaf disks supported on the tops of the chambers. After 24 hrs, the number of adults on the leaf disks were counted. At least four concentrations (%, v/v) of each test product or compound were evaluated along with a water check and were replicated at least four times. The data were converted to the number of adults not on the leaf disks and the data were subjected to probit analyses using SAS. The concentrations required to repel 50% of the whitefly adults (RC_{50}) were calculated for each product and compound and were compared with the RC_{50} of Sunspray Ultrafine Oil, a commercial product that has been reported to have repellent activity against whitefly adults.

Use of Laboratory Bioassay to Screen Compounds for Repellency. Thirty products or compounds were evaluated using the bioassay (Table 1). The commercial products Bio Crack® (garlic extract), Organocide® (sesame and fish oils) and Pepper Wax® (capsacin), that are sold as having repellent properties for agricultural insect pests, were not as repellent to the silverleaf whitefly as the standard Sunspray Ultrafine Oil. Other commercial products including Dawn® detergent, Neemix®(azadirachtin), Prime Oil® and Trilogy®(neem oil) that were thought to have some repellent activity were no more repellent to the whitefly than Sunspray Ultrafine Oil. There was little or no rate response to Envirepel (garlic juice), which is also sold as a repellent. Of the other products evaluated, only citronellal, geranium oil, ginger oil, hamlin oil (citrus oil), olive oil and winter green oil had higher repellent properties than did Sunspray; however, the RC_{50} values were not greatly lower than Sunspray. Combinations of certain products were 15-30 times more repellent than Sunspray alone. All of the non-commercial components were formulated with 1% Tween 20 in order to make water preparations. Better formulations of these components might improve their repellent properties.

Greenhouse Bioassay. In the first greenhouse bioassay, limonene, ginger oil, olive oil and Sunspray Ultrafine Oil were compared with water for impact on oviposition and virus transmission by the silverleaf whitefly on tomato. Trays of 32 tomato seedlings each were sprayed to run-off with 0.25% (v/v) concentrations each of the test materials and, after drying, were placed in organdy-covered cages in the greenhouse. Whitefly adults collected from a colony maintained in the laboratory on tomato plants infected with tomato mottle geminivirus (ToMoV) were released into the cages at the rate of 10/plant. Three days later the plants were treated with imidacloprid to kill the whitefly adults. After three more days the number of whitefly eggs were counted on 10 randomly selected plants from each tray. The plants were then examined weekly for three weeks for the presence of symptoms of ToMoV. The treatments were replicated three times.

Significantly fewer eggs were deposited on all chemically treated plants relative to water treated plants (**Table 2**). No differences among chemical treatments were observed. The Sunspray Ultrafine Oil and olive oil treatments resulted in significantly lower proportions of plants with symptoms of ToMoV compared to the water treatment.

A similar study was conducted with TYLCV (**Table 3**).

The results of these studies suggest that the repellency of different products and compounds can be ascertained quickly in the laboratory and that the repellency of at least some of the materials is strong enough to reduce oviposition and virus transmission by the silverleaf whitefly, even under severe whitefly adult density. Additional studies are needed to evaluate other potential repellents in the laboratory, particularly different combinations and concentrations of products and compounds indicating repellency. These studies need to be followed by additional greenhouse evaluations, both in an experimental setting and in a commercial setting.

C. OTHER PRODUCTS.

Actara (from Syngenta, with a chemistry similar to imidacloprid, the chemical that provides the best chemical control of whiteflies), and **Fulfill** (developed as an aphid anti-feedant) were evaluated for their ability to interfere with whitefly transmission of TYLCV. **Actara** worked well, as expected, and performed in a similar manner to imidacloprid. However, Actara will have limited usefulness because of its chemical similarity to imidacloprid and the concern of whitefly resistance to imidacloprid.

Fulfill was demonstrated to have a significant impact on whiteflies and the transmission of TYLCV-Is. We found that at the label rate (0.291g/L Fulfill 50WG plus 2.5 ml/L NIS), Fulfill provided protection for 4 days. However, Fulfill provided protection from virus transmission for 7 days at a higher rate (0.582g/L Fulfill 50WG plus 2.5 ml/L NIS). Fulfill has a different chemistry than other insecticides in current use and could be very helpful in management of whiteflies and geminiviruses in transplants. We worked successfully with Syngenta to alter the label from exclusion from use in planthouses to permitted use in planthouses.

Objective 3. Evaluate plant growth promoting rhizobacteria (PGPRs) and other biologically based products for protection of plants from infection by TYLCV.

Plant Growth Promoting Rhizobacteria (PGPRs). Thirty isolates of PGPRs were obtained from J. Kloepper. All were evaluated in replicated experiments for their ability to stimulate resistance to TYLCV. Though all the isolates stimulated growth of tomato transplants, none had any effect on the infection rate of TYLCV in tomato transplants.

Commercial Products. We evaluated **Messenger** (Eden Bioscience), which is reported to stimulate resistance to numerous pathogens. Messenger was tested at three rates as a foliar spray. Neither rate of Messenger had any effect on the infection rate of TYLCV in tomato transplants.

We also tested **Actigard** (Syngenta). This was applied as a soil drench and was evaluated for its ability to protect plants from infection in two experiments. At the initial rates tested (0.07 and 0.04 g ai/L of a 50WP formulation) Actigard was observed in both experiments to increase TYLCV-Is infection rates. We have also evaluated Actigard at 3 rates (0.0262 g/L, 0.0092 g/L, and 0.0046 g/L) in a foliar application and it was found to have no effect on transmission rates. We also test 6 rates of Actigard in a soil drench application and the two highest rates caused a slight decrease in the number of TYLCV infected transplants. However these rates are not economical for transplant growers to use.

Objective 4. Identify which plant species commercially produced in Florida are susceptible to infection by TYLCV.

Tomato yellow leaf curl virus (TYLCV), is a concern for tomato growers, transplant producers, and producers of ornamental plants in the Caribbean and southeastern U.S. This study was conducted to identify primarily ornamental plants that can be infected by TYLCV. Adult whiteflies, reared on TYLCV-infected tomato plants, were placed on 94 species within 29 plant families and allowed to feed. The plants were then tested by PCR and dot spot hybridization to determine if they were susceptible to TYLCV. Knowledge of the plant hosts of TYLCV is important for the development of effective disease management strategies.

Eight new host species are reported (*Arabidopsis thaliana*, *Browallia speciosa*, *Limonium sinuatum, Nicotiana langsdorfii*, *Petunia* x *hybrida, Physalis ixocarpa, Physalis pruinosa, Solanum capsicoides*) and we confirmed the ability of this isolate of TYLCV to infect six hosts previously reported from other locations in the world: (*Datura stramonium*, *Eustoma grandiflorum, Lycopersicum pimpinellifolium, Nicotiana benthamiana, Nicotiana tabacum*, *Phaseolus vulgaris*) were confirmed as hosts of this isolate of TYLCV.

Of the new hosts, browallia (*Browallia speciosa*), statice (*Limonium sinuatum),* ground cherry (*Physalis pruinosa*), and flowering tobacco (*Nicotiana langsdorfii*) and are produced in Florida but to a limited extent. Petunia (*Petunia* x *hybrida*) is a major annual plant species produced in Florida and is grown throughout the state in landscapes and containers. Tomatillo (*Physalis ixocarpa*) is a field crop grown to a limited extent in transplant houses and fields. Red tropical soda apple (*Solanum capsicoides*) is a weed that occurs primarily in cattle-grazed land.

Almost as important as knowing the hosts, is knowing which plants are immune. The following plants were inoculated and were not able to be infected: **Anacardiaceae;** *Schnius terebinthifolius* Raddi (Brazilian pepper), **Apocynaceae;** *Catharanthus roseus* (L.) G. Don (Vinca), **Araceae;** *Caladium x hortulanum* ‘White Christmas’ and ‘Frieda Hemple’ (Caladium), **Asclepiadaceae;** *Asclepias sp.* L. (Milkweed), **Asteraceae;** *Ageratum houstonianum* Mill. ‘Royal Hawaii’ (Blue mink), *Calendula officinalis* L. ‘Calypso’ (Pot marigold), *Centaurea cineraria* L. (Dusty Miller), *Centaurea cyanus* L. (Bachelor’s-button), *Chrysanthemum morifolium* L. ‘Ponoma’ (Chrysanthemum), *Emilia fosbergii* Nicolson (Florida Tassel-flower), *Helianthus annuus* L. ‘Mammoth’ (Sunflower), *Melampodium paludosum* L. ‘Derby’ (Yellow Jaune), *Rudbeckia hirta* L. (Blackeye Susan), *Sonchus oleraceus* L. (Sow thistle), *Tagetes erecta* L. ‘Little Yellow Hero’ (American marigold), *Tagetes patula* L. ‘Bonanza Bee’ (French marigold), *Tithonia rotundifolia* (Hemsl.) A. Gray ‘Fiesta del Sol’ (Mexican sunflower), **Balsaminaceae;** *Impatiens wallerana* Hook. F. “Impact White’ (Impatiens), **Begoniaceae;** *Begonia semperflorens* Link & Otto (Wax Begonia), **Brassicaceae;** *Brassica oleracea* L. var. *acephala* DC ‘Vates’ (collard), *Brassica oleracea* L. var. *capitata* ‘Earliana’ (cabbage), *Brassica rapa* L. var. *rapa* (DC) Metzg. (turnip), *Capsella bursa-pastoris* L. (Sheperd’s purse), **Caryophyllaceae;** *Diathus chinensis* L. ‘Baby Doll’ (Chinese pink), *Gypsophila elegans* L. (Baby’s breath), **Chenopodiaceae;** *Chenopodium ambrosioides* L. (Mexican tea), **Cucurbitaceae;** *Citrullus lanatus* (Thurb.) Matsum & Nakai ‘Charleston Grey’ (watermelon), *Cucumis melo* L. var. *cantaloupensis* ‘Top Mark’ (cantaloupe), *Cucumis sativus* L. ‘Dasher II’ (cucumber), *Cucurbita pepo* L. ‘Spineless Beauty’ (zucchini squash), *Momordica charantia* L. (Bitter gourd), **Euphorbiaceae;** *Euphorbia hypericifolia* L. (Graceful sandmat), *Euphorbia marginata* Pursh (Snow-on the-Mountain), *Euphorbia pulcherrima* Willd. ex Klotzsch ‘Freedom’ (Poinsettia), F**abaceae;** *Crotalaria rotundifolia* J.F. Gmel (Rabbitbells), *Pachyrhizus erosus* (L.) Urb. (Jicama), *Phaseolus limensis* L. Macfady (Lima bean), *Phaseolus vulgaris* L. ‘Top Crop’ (Common bean), *Vicia faba* ‘Broad Windsor Long Pod’ (Fava bean), *Vinga sesquipedalis* ‘Yard Long’ (Asparagus bean), *Vigna unguiculata* (L.) Walp. ‘California Blackeye’ (Cowpea), **Gentianaceae;** *Eustoma grandiflorum* ‘Echo Blue’ (Lisianthus), **Geraniaceae;** *Pelargonium x hortorum* ‘Ringo Red’ (Geranium), **Lamiaceae;** *Coleus blumei* Lour. (Coleus), *Lavendula sp.* ‘Midcole Blue’ (Lavender), *Salvia splendens* ‘Vista Red and White’ (Salvia), **Lythraceae;** *Cuphea hyssopifolia* (False Heather), **Malvaceae;** *Abelmoschus moschatos* (Pacific orange scarlet), *Abutilon theophrasti* Medik. (Velvetleaf), *Alcea rosea* L. (Hollyhock), *Goppypium hirsutum* L. ‘Delta Pina Acala 90’ (Upland cotton), **Myrtaceae;** *Eugenia uniflora* (Surinam cherry), **Onagraceae;** *Ludwigia erecta* (L.) H. Hara (Yerba de Jicotea), *Ludwigia leptocarpa* (Nutt.) H. Hara (Primrose willow), *Oenothera glazioviana* (Scented evening primrose), **Polemoniaceae;** *Ipomopsis sp.* Michx. ‘Hummingbird Mix’ (Ipomopsis), **Portulacaceae;** *Portulaca sp.* L. (Purslane), **Rosaceae;** *Fragaria virginiana* Duchesne ‘Sweet Charlie’ (strawberry), **Rubiaceae;** *Pentas lanceolata* ‘New Look Rose’ (Pentas),

Scrophulariaceae; *Antirrhinum majus* (Snapdragon), *Angelonia angustifolia* (Narrowleaf Angelon), **Solanaceae;** *Brugmansia x candida*, *Capsicum annuum* 'Red Rooster Spur' (Red pepper), *Cestrum nocturnum* L. (Night-flowering Jessamine), *Nicotiana alata* 'Hummingbird Rose' (Winged tobacco), *Physalis alkekengi* (Chinese lantern), *Physalis angustifolia* Nutt. (Coastal groundcherry), *Physalis floridana* (Husk tomato), *Solandra maxima*, *Solanum americanum* (American black nightshade), *Solanum capsicoides* (Red tropical soda apple), *Solanum diphyllum* L. (Twoleaf nightshade), *Solanum eleagnifolium* (Silverleaf nightshade), *Solanum melongena* 'Thai Long Green' and 'Thai Round Green' (Oriental eggplant), *Solanum seaforthianum* (Brazilian nightshade), *Solanum torvum* (Turkeyberry), *Solanum viarum* (Yellow tropical soda apple), **Verbenaceae;** *Verbena hortensis* 'Obsession' (Garden Verbena), *Lantana camara* (Lantana), **Violaceae;** *Viola splendid* 'Blue & Yellow', *Viola x wittrockiana* (Pansy).

Outputs of this Project:

<u>Presentations:</u>

Polston, J. E. 2001. "Management of Tomato Yellow Leaf Curl Virus in Florida". Third International Geminivirus Symposium, 24-28 July 2001, Norwich, England. (Invited)

Polston, J. E. and <u>R. J. McGovern</u>. 2001. "New and emerging disease problems: *Tomato yellow leaf curl virus*". 17th Conf. On Insect and Disease Management on Ornamentals. 25-27 Feb. 2001, Orlando, FL.

Polston, J.E. and D.J. Schuster, New Tools for Management of Whitefly-transmitted Geminiviruses . pp. 17-19 <u>In:</u> 2000 Florida Tomato Institute Proceedings, PRO-516, C.S. Vavrina, ed., Univ. of Florida and Citrus and Vegetable Magazine. 5 Sept. 2001 Naples, FL.

J. E. Polston, T. Sherwood, and D. J. Schuster. 2002. Effect of Pymetrozine on Transmission of *Tomato Yellow Leaf Curl Virus* by the Whitefly, *Bemisia tabaci.* Proc. 17th National Tomato Disease Workshop. 7-9 Nov. 2001, W. Palm Beach, FL (invited).

<u>Conference Proceedings:</u>

Polston, J.E. and R.J. McGovern. 2001. New and emerging disease problems: *Tomato yellow leaf curl virus*. pp. 7-10 <u>In</u>: Proc. 17th Conf. On Insect and Disease Management on Ornamentals. 25-27 February 2001, Orlando, FL.

Polston, J.E. and D.J. Schuster, New Tools for Management of Whitefly-transmitted Geminiviruses . pp. 17-19 <u>In:</u> 2000 Florida Tomato Institute Proceedings, PRO-516, C.S. Vavrina, ed., Univ. of Florida and Citrus and Vegetable Magazine. 5 Sept. 2001 Naples, FL.

J. E. Polston, T. Sherwood, and D. J. Schuster. 2002. Effect of Pymetrozine on Transmission of *Tomato Yellow Leaf Curl Virus* by the Whitefly, *Bemisia tabaci.* Proc. 17th National Tomato Disease Workshop. (In press).

<u>Manuscripts:</u>

J. E. Polston and T. Sherwood. 2002. Pymetrozine Interferes with Transmission of *Tomato*

Yellow Leaf Curl Virus by the Whitefly, *Bemisia tabaci* (*Hemiptera: Aleyrodidae*). Florida Entomologist (submitted).
J. E. Polston, T. Sherwood, and R. J. McGovern. 2002. Experimental Host Range of a Florida Isolate of *Tomato Yellow Leaf Curl Virus*. HortScience (in preparation).

Popular Press/Extension Publications:

Polston, J.E. 2000. Cultural Control of TYLCV. Manatee Vegetable Newsletter May/June issue. 1 pg.

Polston, J.E., P.D. Roberts, and K. Pernezny. 2000. Evaluation of Chemicals for the Control of Whiteflies and Transmission of *Tomato yellow leaf curl virus* in Planthouses. Vegetable IPM Newsletter No. 4. 1 pg.

Polston, J.E. and D.J. Schuster. 2000. Tools for Management of Whitefly-transmitted Geminiviruses. Manatee Vegetable Newsletter Sept./Oct issue. 1 pg.

Polston, J.E., A. Post, and T.A. Sherwood. Evaluation of Actara for Protection of Tomato Transplants from Infection by *Tomato yellow leaf curl virus*. GCREC Research Report BRA 2000-7. Sept. 2000. Bradenton, FL. 6 pg.

Post, A., and J.E. Polston. Evaluation of Actigard for Protection of Tomato Transplants from Infection by *Tomato yellow leaf curl virus*. GCREC Research Report BRA 2000-8. Sept. 2000. Bradenton, FL. 6 pg.

Polston, J.E., A. Post, and T.A. Sherwood. 2000. The Effect of Fulfill on the Transmission of *Tomato yellow leaf curl virus* by the Whitefly, *Bemisia tabaci*, to Tomato Transplants. GCREC Research Report BRA 2000-15. Oct. 2000. Bradenton, FL. 8 pg.

Application of These Results by the Florida Agricultural Industry:

Many transplant producers have told me that they are now using Fulfill routinely and are getting good results. Many stated that after using Fulfill they had no to few complaints from their customers regarding virus-infected transplants. Although hard to confirm, the use of Fulfill by Florida transplant producers should reduce or slow down the introduction of TYLCV into other states (or countries).

I have talked to several greenhouse tomato growers about using UV-absorbing plastics to minimize the incidence of virus-infected plants in their houses. I do not know how many greenhouses are now using this new approach, although several are considering testing the plastic next time they need to replace their plastic.

Table 1. Comparison of various compounds and products for repellency to silverleaf whitefly adults in the laboratory.

Material	Intercept	Slope	RC_{50}[1]	RR_{50}[2]	P
Sunspray Ultrafine Oil®	1.39	1.77	0.15	-----	<0.01
Bio Crack®	-3.03	1.68	63.67	424.5	0.50
Capsacin		>0.1[3]			
Castor Oil	0.41	1.28	0.48	3.2	<0.01
Cedar Oil	0.44	0.56	0.16	1.1	<0.00001
Cineole	0.32	0.95	0.46	3.1	0.02
Citronellal	**2.79**	**2.67**	**0.09**	**0.6**	**0.33**
Dawn® detergent	0.63	1.14	0.28	1.9	0.10
Envirepel®	-1.73	-0.08	3.63E-21	—	0.01
Geranium Oil	**1.60**	**1.76**	**0.12**	**0.8**	**0.01**
Ginger Oil	**3.92**	**3.26**	**0.06**	**0.4**	**0.05**
Hamlin Oil	**0.80**	**0.64**	**0.06**	**0.4**	**0.04**
Hyssop	0.09	0.44	0.61	4.1	0.57
Jasmonic Acid	0.13	0.78	0.69	4.6	0.02
Lavender	0.21	1.10	0.65	4.3	<0.00001
Limonene	2.36	3.59	0.22	1.5	<0.01
Neemix®	-1.73	1.79	9.36	62.4	0.43
Olive Oil	**2.38**	**1.49**	**0.025**	**0.2**	**0.0002**
Organocide® (New)	-0.78	3.83	1.60	10.7	0.07
Organocide® (Old)	-0.29	2.07	1.39	9.3	0.12
Pepper Wax®	-9.29	7.01	21.13	140.7	0.001
Prime Oil®	-0.14	0.66	1.61	10.7	0.27
Rosemary	-0.46	1.20	2.43	16.2	0.0005
Sage	0.06	-0.12	1.39	9.3	0.09
Sesame Oil	0.42	0.82	0.30	2.0	0.14
Tagetes	0.32	0.69	0.53	3.5	0.0002
Tansy	-0.98	2.25	2.73	18.2	0.13
Trilogy®	-0.78	2.31	2.17	14.5	0.19
Tween 20®	-1.73	1.53	13.45	89.7	0.36
Winter Green Oil	**3.08**	**2.77**	**0.08**	**0.5**	**<0.01**
Combination No. 1	**3.92**	**1.71**	**0.005**	**0.03**	**0.88**
Combination No. 2	**2.44**	**1.22**	**0.01**	**0.07**	**0.002**

[1]Estimated concentration of test compound (% v/v) required to repel 50% of an adult whitefly population.
[2]Repellency rates based upon RC_{50} values relative to Sunspray Ultrafine Oil as the standard.
[3]Higher concentrations were too innocuous to handle.

Table 2. Effect of various compounds and a commercial product on oviposition and *Tomato mottle virus* transmission by silverleaf whitefly adults on tomato transplants in the greenhouse.

Material	No. Eggs/Plant	% Plants with Virus Symptoms
Ginger oil	137 a	46.0 bc
Limonene	166 a	39.2 bc
Sunspray Ultrafine Oil®	191 a	24.0 ab
Olive oil	218 a	18.0 a
Water	379 b	58.6 c

Table 3. Effect of various compounds and a commercial product on oviposition and *Tomato yellow leaf curl virus* transmission by silverleaf whitefly adults on tomato transplants in the greenhouse.

Material	No. Eggs/Plant	% Plants with Virus Symptoms
Ginger oil	137a	46.0bc
Limonene	166a	39.2bc
Sunspray Ultrafine Oil®	191a	24.0ab
Olive oil	218a	18.0a
Water	379b	58.6c

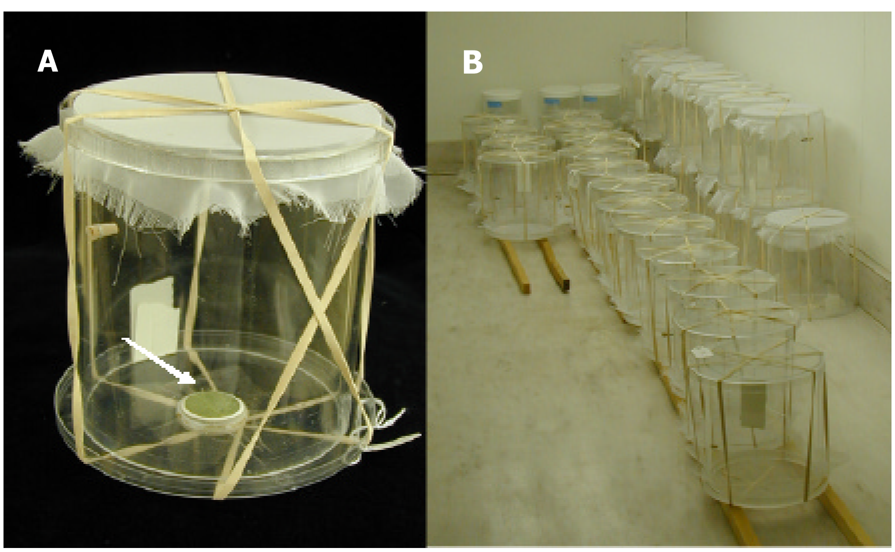

Figure 1. A laboratory bioassay to measure the ability of a compound to repel adult whiteflies. **A.** Cage (shown upside down) designed to confine whitefly with leaf disk that has been treated with test compound. Leaf disk indicated by arrow. **B.** Experiment in progress showing cages in correct orientation with whiteflies.