Citrus whitefly adults on citrus leaves.

Citrus whitefly parasites established in California

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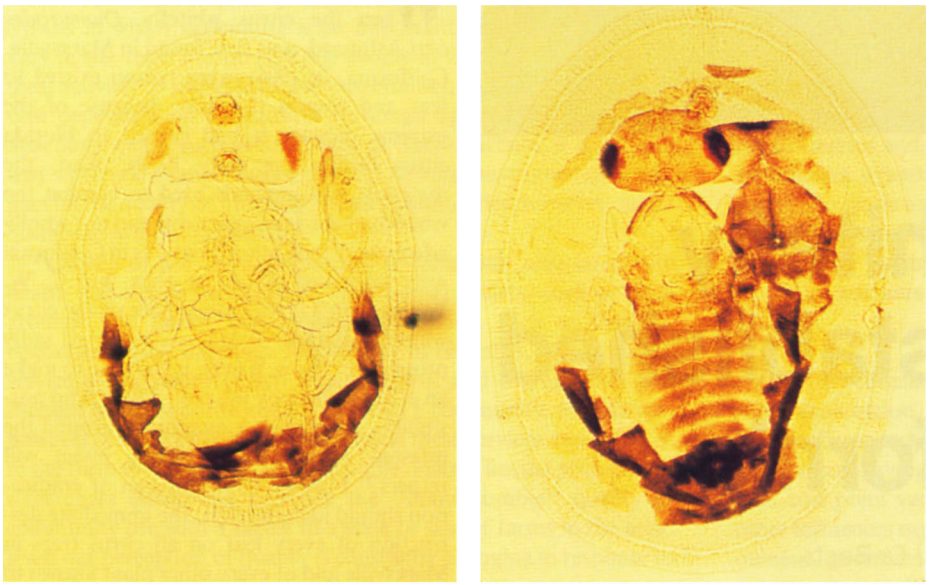
Adult female whitefly parasite, *Encarsia lahorensis*, is less than 1 mm long.

When the citrus whitefly, *Dialeurodes citri* Ashmead, was first found in Marysville, California, in 1906, every reason existed to fear and respect this pest, because of the extreme damage it had caused to Florida citrus during the early 1900s. Also, the materials and methods used to combat the whitefly there were expensive and not wholly adequate. Eradication measures in California were suggested almost at once, but C. W. Woodworth's (1907) assessment of the citrus whitefly invasion of Marysville proved sadly prophetic: "Now, if ever, is the time to make an effort to destroy the pest. There is no possibility of throwing a quarantine around the infested district that a flying insect will respect." Further, "A campaign of eradication should include: first, the immediate destruction of every leaf on all citrus trees in Marysville and of every other plant known to furnish sustenance to this insect." Finally, however, he states, "It may be that already the insect has gotten beyond control, but the chance of eradication is certainly worth the effort."

In spite of the early measures against the citrus whitefly, it continued to spread through California's citrus-growing areas. The ultimately unsuccessful eradication efforts were continued from time to time over a 62-year period in 14 California counties. The last eradication project ended in San Diego during 1968, closing an era that saw trials employing the manual destruction of trees, cyanide fumigation, and finally the repeated application of chemicals such as DDT, carbaryl, and malathion. All came to naught, and today citrus whitefly still occurs in localities throughout California's citrus areas.

At present, we know of only one case where this insect is causing economic injury,

Encarsia sp. laying eggs in fourth-stage larva of citrus whitefly.



Cast pupal skins of *Encarsia lahorensis:* On left, single cast skin in fourth-stage citrus whitefly from which a female parasite is emerging. Right, partially consumed female *E. lahorensis* pupa and the cast pupal skin of an emerging male *E. lahorensis.*

but we respect its future potential in an ever-changing environment and hence have imported natural enemies in hopes of reducing that potential.

First foreign exploration for natural enemies

When the citrus whitefly was first discovered in Florida during the late 1800s, the U.S. Department of Agriculture began work on measures to obtain economic control. Fumigation with cyanide, spraying with various insecticides, and the use of several parasitic fungus "diseases" present in Florida gave mixed results. Later, oil sprays were used with some success.

An alternate plan was afoot, however, during the early 1900s: foreign exploration for natural enemies, undertaken by R. S. Woglum, then of the U.S. Department of Agriculture. Thanks to collaboration with George Compere of California (and by utilizing the reference collections of William Maskell), Woglum and A. L. Quaintance determined the native range of citrus whitefly to be the tropical or semitropical climatic areas of the Orient. Woglum left New York by steamship on July 31, 1910, to search "India and the Orient" for parasites and predators of the citrus whitefly.

In the Indian Museum in Calcutta, he found curated specimens of the citrus whitefly, which gave him a definitive starting point for his search. He then traveled extensively throughout India, often by foot, oxcart, on horseback, and by riverboat, looking at representative citrus stands. In Saharanpur he discovered the coccinellid predator *Serangium flavescens* (Motschulsky) feeding on the citrus whitefly, and in Lahore he discovered the internal paraite *Encarsia* (= *Prospaltella*) *lahorensis* (Howard). Five months later he left India for Burma, China, and the Philippines. After hospitalization in the Philippines and four more months of searching in the Orient, he returned to India to collect and prepare natural-enemy cultures for transportation to the United States.

Fifteen months after he had left New York, Woglum and his "mobile insectary" of large Wardian cages began the return trip to Florida. In five weeks he reached New York by ship and left immediately for Orlando, Florida, arriving with live specimens of both *E. lahorensis* and *S. flavescens.* There, due to unsatisfactory field and laboratory conditions, all the natural enemies were lost. For some inexplicable reason, importation work was not repeated until our recent efforts.

Biological control in California

In 1966, we essentially took up where the work had ended in 1911, when we began introduction of natural enemies of the citrus whitefly from Pakistan, India, Japan, and Hong Kong. We also searched for natural enemies of the cloudy-winged whitefly, *Dialeurodes citrifolii* (Morg.), a closely related species, in Mexico and South America. During 1966-77, we imported six parasite species and four predator species from throughout the world. Four of the six parasite species are new and, as yet, undescribed.

The imported natural enemies were processed through quarantine, then insectary-cultured in San Diego, and colonized in San Diego, Orange, and Sacramento counties. Of the parasites imported, *Eretmocerus* sp. from Japan, *E. lahorensis* from India and Pakistan, and *Encarsia* sp. from India were recovered in the field following colonization. *Eretmocerus* sp. could no longer be recovered after appoximately a year in the field, although it did reduce the citrus whitefly population on a field study site in San Diego.

When we originally imported *E. lahorensis* from India and Pakistan, it was propagated in two separate cultures. Laboratory crossing tests showed the parasites to be the same species, and the cultures were then combined. The complicated biology of the parasite made laboratory and field colonies difficult to initiate. Although mated females produce progeny normally as primary parasites, the males develop as hyperparasites on the im-

mature stages of their own species and on other parasite species (*Eretmocerus* sp.). To obtain males we first had to introduce mated females into a host system so that immature females would be produced. This was followed by introduction of unmated females, whose progeny would be male, into the same system so that the virgin females would have the required previously parasitized hosts in which they could oviposit male producing eggs and thus enable the culture to establish continuity.

Encarsia lahorensis has now been established in Orange, Sacramento, and San Diego counties in California for approximately eight to ten years. It has proved to be very efficient at searching out the host whitefly, as evidenced by its ability to reproduce at extremely low host densities. It is, however, slow to disperse from colonization sites in California and does not always respond rapidly (i.e., reproduce) to host population increases.

During 1979, in a small study grove in Orange County, we were able to observe the efficacy of *E. lahorensis*. Citrus whitefly populations were increasing rapidly on study trees after insecticidal treatments had ceased. Individual citrus leaves with 100 to 200 live immature whitefly were common on some trees. Yet, within a period of only three to four months, the whitefly population was completely reduced and subsequently held to low levels by *E. lahorensis*. During 1980 no marked increase of citrus whitefly occurred in this study grove, and parasitization by *E. lahorensis* remained at high levels.

In other study sites in Orange and San Diego counties, citrus whitefly populations have also been greatly reduced following establishment of *E. lahorensis*. In a small study grove in San Diego, where citrus whitefly populations had been treated during 1966 eradication attempts, once massive populations have been reduced to an average of less than one live immature whitefly per leaf. The whitefly population density has remained at these low levels for more than 10 years, and rates of parasitization by *E. lahorensis* remain high; checks in 1973-74 showed that 60 to 100 percent of fourth instar citrus whitefly were parasitized. Investigations of this study site in 1978 and 1979 showed the same trends.

Encarsia lahorensis appears to be a valuable and desired component of the natural enemy complex on citrus whitefly. We have provided live specimens of this parasite to researchers in Florida, France, Italy, Russia and Turkey, and *E. lahorensis* is now established in Florida and Italy. We are as yet unsure of results in Russia and Turkey. Recent reports from collaborators in Florida indicate that *E. lahorensis* is now bringing about biological control of citrus whitefly there some 80 years after invasion. In Italy, importation of the parasite is also resulting in biological control of the whitefly.

Natural Enemies of Citrus Whitefly Imported into California

Country of origin	Parasites	Predators
India	**Encarsia (= Prospaltella)†*	
	lahorensis	*Catana parcesetosa*
	**Encarsia* sp.	
Pakistan	**E. lahorensis*	*Brumoides suturalis*
Japan	*Eretmocerus* sp.	
	Encarsia citri	
	Encarsia sp.	
Hong Kong	*Encarsia ?citri*	
USA (Florida)		**Delphastus pusillus*
		Nephaspis gorhami

*Established.
†We are using the generic designation *Encarsia*, although the designation *Prospaltella* has been used extensively in the literature. Recent publications have affected this nomenclatural change.

Additionally, the previously mentioned *Encarsia* sp. from India has been established in San Diego County since 1969-70 and was recovered in 1977, following further colonization, in Orange County. This species is uniparental (that is, it reproduces without males), and it is a beautiful robust parasite. It, too, appears to be an extremely effective searcher for hosts at low densities, but we have not yet seen it reproduce rapidly in response to a growing citrus whitefly population. This *Encarsia* sp. has shown dispersal capabilities far superior to *E. lahorensis*.

The only imported predator readily recovered in the field following colonization is *Delphastus pusillus* from Florida. It has not proved to be exciting, although even its apparently minimal effects may be cumulatively positive. We have also observed various native general predators, such as coccinellids, green lacewings, and dusty wings (coniopterygids), feeding on the citrus whitefly in California.

Current status

Citrus whitefly is not generally an important economic pest of citrus in California; it may never prove to be. It occurs mainly in dooryard plantings, but was found in 1979 commercial citrus in Irvine Ranch in Orange County and became so dense during the summer of 1980 that an oil treatment was applied. Several whitefly parasitized by *E. lahorensis* and *Encarsia* sp. were recovered following intense searches in this grove in early summer of 1980, but the few parasite pupae found were dead. Examinations of tens of thousands of immature whitefly just before treatment yielded no evidence of either parasite.

The citrus whitefly has a remarkable potential for population explosion. Like other whitefly species, it produces honeydew, and the attendant sooty mold fungus damages citrus trees and fruit. Defoliation in the fall due to stress and concurrent increased mite populations have also frequently been observed when the whitefly reaches high densities. It is hoped that, as the imported natural enemies become more generally dispersed, the citrus whitefly may be precluded from reaching its pest potential.

Conclusions

The case of citrus whitefly in California is an example of the failure of a total eradication program as compared with a control strategy. In our experience alone, we have conducted biological control research with four insect invaders in California that originally were the object of total eradication programs: citrus whitefly, California red scale, woolly whitefly, and striped mealybug. Millions of dollars were spent in these eradication attempts, all of which ultimately failed. The fact that today three of these invaders are minor pests or nonpests is due in large part to imported parasites. By choosing to utilize, wherever indicated, methods such as biological control as alternatives to total eradication, we may be able to minimize use of insecticides, save millions of dollars, and achieve permanent and safe pest management.

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