

BIOLOGICAL CONTROL OF CITRUS PESTS IN TAIWAN

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HISTORICAL BACKGROUND OF BIOLOGICAL CONTROL IN TAIWAN

The sustained work on the biological control of citrus pests in Taiwan was initiated 1902 when the cottony-cushion scale, *Icerya purchasi* Mask., entered Taiwan attached on *Acacia* trees introduced from Australia. The infestation of this scale on citrus was heavy in the early years following its establishment. During that period Dr. Shiraki found 3 native species of natural enemies, *Chrysopa* sp., *Pteromalus* sp., and a fungus, *Empusa* sp., which attacked the scale but were not effective in controlling this invader. In 1909 he made two importations of *Rodolia cardinalis* Muls. from New Zealand. It was reared and released in northern Taiwan. This introduced predator quickly became established. So rapid was its increase and spread that it together with a native coccinellid, *Rodolia pumila* Weise, became the major controlling agent against this pest. Thereafter, the scale populations were so reduced that it became a minor pest.

Nipaecoccus filamentosus (Cocker.) and *Planococcus citri* (Risso) are two common citrus mealybugs attacking a wide range of fruit trees and ornamental plants. The coccinellid predator, *Cryptolaemus montrouzieri* Muls., was introduced into Taiwan from New Zealand in 1909 by Shiraki. This predator readily became established in northern Taiwan and was considered to be a good predator because of its voracious appetite. However, the climatic conditions of this island proved to be unsuitable and it was not able to survive in adequate numbers through the winter. Therefore, the mealybug infestations usually reached injurious levels in spring and early summer. This coccinellid predator also seemed to be inactive during the hot summer months. Fortunately, 2 natural enemies, *Anagyrus sawadai* Ishii, and *Scymnus (Nephus) ryuguus* Kamiya, were found; the former species being tolerant to hot weather. It has always been the most effective natural enemy of mealybugs in Taiwan.

CITRUS PESTS IN TAIWAN

More than 150 species of insects and mites attacking citrus have been recorded from Taiwan. The common species and their pest status at present are listed in Table 1.

NATURAL ENEMIES OF CITRUS PESTS IN TAIWAN

There are more than 100 species of parasitoids and predators of citrus pests recorded from Taiwan. Listed in Table 2 are the major citrus pests and their natural enemies.

Table 1. A list of citrus pests and their importance in Taiwan

Common name	Scientific name	Pest status		
		Major	Occasional	Minor
Soft scales	<i>Ceroplastes rubens</i>			V
	<i>Coccus hesperidum</i>			V
	<i>C. viridis</i>	V		
	<i>Pulvinaria polygonata</i>			V
	<i>Saissetia coffeae</i>			V
Fluted scale	<i>Icerya purchasi</i>			V
Armored scales	<i>Aonidiella citrina</i>			V
	<i>Aspidiotus destructor</i>			V
	<i>Chrysomphalus ficus</i>	V		
	<i>Lepidosaphes beckii</i>		V	
	<i>Parlatoria pergandei</i>	V		
	<i>P. zizyphi</i>		V	
Mealybugs	<i>Nipaecoccus filamentosus</i>	V		
	<i>Planococcus citri</i>	V		
White flies	<i>Aleurocanthus spiniferus</i>	V		
	<i>Bemisia giffardi</i>			V
Aphids	<i>Aphis gossypii</i>	V		
	<i>Aphis citricola</i>	V		
	<i>Myzus persicae</i>		V	
	<i>Toxoptera aurantii</i>			V
	<i>T. citricidus</i>		V	
Citrus psylla	<i>Diaphorina citri</i>	V		
Stinkbugs	<i>Nezara viridula</i>		V	
	<i>Pendulinus nicobarensis</i>		V	
	<i>Rhynchocoris humeralis</i>	V		
Thrip	<i>Thrips hawaiiensis</i>		V	
Fruit fly	<i>Dacus dorsalis</i>	V		
Beetles	<i>Adoretus formosanus</i>		V	
	<i>Anomala expansa</i>		V	
	<i>Anoplophora maculata</i>	V		
	<i>Hypomeces squamosus</i>		V	
Butterflies	<i>Papilio bianor kotoensis</i>			V
	<i>Princeps demoleus</i>	V		
Moths	<i>Adoxophyes fasciata</i>			V
	<i>Alcis acaciaria</i>			V
	<i>Cania bilinea</i>		V	
	<i>Clania preyeri</i>		V	
	<i>Cryptoethelca minuscula</i>		V	
	<i>Homona menciata</i>		V	
	<i>Nagadopsis shirakiana</i>		V	
	<i>Notolopharus australis posticus</i>			V

Table 1. continued

Common name	Scientific name	Pest status		
		Major	Occasional	Minor
	<i>Orthocraspeda trima</i>		V	
	<i>Parasa consocia</i>		V	
	<i>Pasychira mendosa</i>			V
	<i>Phyllocnistis citrella</i>	V		
	<i>Porthesia taiwana</i>			V
	<i>Tiracola plagiata</i>			V
Mites	<i>Brevipalpus obovatus</i>		V	
	<i>Panonychus citri</i>	V		
	<i>Phyllocoptruta oleivora</i>	V		
Snails	<i>Achatina fulica</i>		V	
	<i>Bradybaena similaris</i>		V	
Slug	<i>Limacella agrestisuavians</i>		V	

Table 2. Citrus pests and their natural enemies in Taiwan

	Pest	Natural enemy	Kind of natural enemy ¹	Frequency of occurrence
Soft scales	<i>Coccus viridis</i>	<i>Aneristus cerphastae</i>	pa	common
		<i>Coccophagus tibialis</i>	"	"
		<i>Microterys speciosus</i>	"	"
	<i>Pulvinaria polygonata</i>	<i>Aneristus cerphastae</i>	"	"
		<i>Coccophagus tibialis</i>	"	"
	<i>Saissetia coffeae</i>	<i>Aneristus ceroplastae</i>	"	localized
<i>Coccophagus tibialis</i>		"	"	
<i>Microterys speciosus</i>		"	"	
Fluted scale	<i>Icerya purchasi</i>	<i>Cryptochaetum iceryae</i>	pr	rare
		<i>Rodolia cardinalis</i>	"	common
		<i>R. pumila</i>	"	"
Armored scales	<i>Aonidiella citrina</i>	<i>Prospaltella perniciosi</i>	pa	common
		<i>Telsimia nitida</i>	pr	"
	<i>Aspidiotus destructor</i>	<i>Aphytis holoxanthus</i>	pa	"
		<i>Aspidiotiphagus citrinus</i>	"	"
	<i>Chrysomphalus ficus</i>	<i>Aphytis holoxanthus</i>	"	"
		<i>Aspidiotiphagus lounsburyi</i>	"	localized
		<i>Chrysopa boninensis</i>	pr	common
		<i>Cybocephalus gibbulus</i>	"	localized
		<i>Hemisarcoptes</i> sp.	"	rare
		<i>Pharoscyrnus taoi</i>	"	localized
		<i>Telsimia nitida</i>	"	common
	<i>Lepidosaphes beckii</i>	<i>Aphytis holoxanthus</i>	pa	localized
		<i>A. lepidosaphes</i>	"	"
		<i>Aspidiotiphagus citrinus</i>	"	"
<i>Chrysopa boninensis</i>		pr	common	

Table 2. continued

Pest	Natural enemy	Kind of natural enemy ¹	Frequency of occurrence	
<i>Parlatoria pergandei</i>	<i>Hemisarcoptes</i> sp.	pr	rare	
	<i>Telsimia nitida</i>	"	"	
	<i>Aspidiotiphagus citrinus</i>	pa	"	
	<i>Fusarium coccophilum</i>	f	localized	
	<i>Chrysopa boninensis</i>	pr	common	
	<i>Hemisarcoptes</i> sp.	"	rare	
	<i>Telsimia nitida</i>	"	"	
	<i>P. zizyphi</i>	<i>Aphytis chrysomphali</i>	pa	localized
		<i>A. proclia</i>	"	"
		<i>Aspidiotiphagus citrinus</i>	"	"
<i>Fusarium coccophilum</i>		f	"	
<i>Hypocrella aleyrodis</i>		"	"	
<i>Ophinoectria tetraspora</i>		"	rare	
<i>Sphaerostilbe aurantiicola</i>		"	"	
<i>S. coccophila</i>		"	"	
<i>S. fukuroi</i>		"	"	
<i>Chrysopa boninensis</i>		pr	localized	
<i>Hemisarcoptes</i> sp.	"	"		
<i>Telsimia nitida</i>	"	rare		
Mealybugs	<i>Nipaecoccus filamentosus</i>	<i>Anagyrus sawadai</i>	pa	common
		<i>Cryptolaemus montrouzieri</i>	pr	"
		<i>Scymnus (Nephus) ryuguus</i>	"	rare
	<i>Planococcus citri</i>	<i>Anagyrus sawadai</i>	pa	common
		<i>Cryptolaemus montrouzieri</i>	pr	"
<i>Scymnus (Nephus) ryuguus</i>	"	rare		
Spiny blackfly	<i>Aleurocanthus spiniferus</i>	<i>Amitus hesperidum</i>	pa	localized
		<i>Prospaltella smithi</i>	"	common
		<i>Aegerita webbneri</i>	f	localized
		<i>Aschersonia</i> spp.	"	"
		<i>Acletoxenus</i> sp.	pr	common
<i>Serangium</i> sp.	"	localized		
Aphids	<i>Aphis gossypii</i>	<i>Aphelinus mali</i>	pa	localized
		<i>Trioxys (B.) communis</i>	"	common
		<i>T. (B.) indicus</i>	"	localized
	<i>A. citricola</i>	<i>Aphelinus mali</i>	"	"
		<i>Lipolexis gracilis</i>	"	common
	<i>Toxoptera aurantii</i>	<i>Trioxys (B.) citri</i>	"	localized
		<i>Aphelinus mali</i>	"	"
	<i>Lipolexis gracilis</i>	"	common	
	<i>Aphis gossypii</i>	<i>Asarcina aegrota</i>	pr	localized
	<i>A. citricola</i>	<i>Chrysopa boninensis</i>	"	common
	<i>Toxoptera aurantii</i>	<i>C. formosana</i>	"	localized
	<i>T. citricidus</i>	<i>Coccinella octopunctata</i>	"	"
		<i>C. repanda</i>	"	"
		<i>C. septempunctata</i>	"	"
		<i>Coelophora chinensis</i>	"	"
<i>Epistrophe balteata</i>		"	common	
<i>Lemnia biplagiata</i>		"	"	
<i>L. swinhoei</i>		"	"	
<i>Menochilus sexmaculatus</i>	"	"		

Table 2. continued

	Pest	Natural enemy	Kind of natural enemy ¹	Frequency of occurrence
		<i>Propylaea japonica</i>	pr	common
		<i>Pseudaspidimerus japonensis</i>	"	localized
		<i>Scymnus frontalis quadripustulatus</i>	"	common
Psylla	<i>Diaphorina citri</i>	<i>Diaphorencyrtus aligarhensis</i>	pa	common
		<i>Psyllaephagus</i> sp.	"	localized
		<i>Chrysopa boninensis</i>	pr	"
Stinkbug	<i>Rhynchocoris humeralis</i>	<i>Anastatus formosanus</i>	pa	common
		<i>Tetrastichus</i> sp.	"	localized
Fruit fly	<i>Dacus dorsalis</i>	<i>Opius arisanus</i>	pa	localized
		<i>O. flecheri</i>	"	"
		<i>O. formosanus</i>	"	"
		<i>O. makii</i>	"	"
Butterfly	<i>Princeps demoleus</i>	<i>Trichogramma chilonis</i>	pa	common
Moths	<i>Phyllocnistis citrella</i>	<i>Ageniaspis citricola</i>	pa	common
		<i>Cirrospilus ingennus</i>	"	"
		<i>Tetrastichus</i> sp.	"	localized
	<i>Porthesia taiwana</i>	<i>Apanteles</i> sp.	"	"
		<i>Ichneumonid</i> wasp	"	"
Mites	<i>Panonychus citri</i>	<i>Amblyseius herbicolus</i>	pr	common
		<i>Arthrocnodax occidentalis</i>	"	localized
		<i>Chrysopa boninensis</i>	"	"
		<i>Oligota oviformis</i>	"	common
		<i>Stethorus loi</i>	"	"
	<i>Phyllocoptruta oleivora</i>	<i>Hirsutella thompsonii</i>	f	"

¹ pa = parasitoid, f = fungus, pr = predator.

PROGRESS IN THE BIOLOGICAL CONTROL OF SPECIFIC CITRUS PESTS

The insect pests of citrus in Taiwan comprise diverse groups; the most important of which are scale insects, mealybugs, spiny blackfly, aphids, citrus psylla, stinkbugs, fruit fly, longicorn beetles, citrus dogs, leafminer and the phytophagous mites.

Soft Scales: There are 8 species of soft scales infesting citrus; *Coccus viridis*, *Pulvinaria polygonata*, and *Saissetia coffeae*, being the most common species. Populations of *Pulvinaria polygonata*, and *Saissetia coffeae* are usually kept in check by *Aneristus ceroplastae* and *Coccophagus tibialis*, but they can not keep the population of *Coccus viridis* under economic injury level.

Fluted Scales: Three species of *Icerya* were recorded attacking citrus in Taiwan of which *Icerya purchasi* was the most injurious one before *Rodolia cardinalis* was imported. The imported predator is known to be an effective predator for the control of *I. purchasi*. Meanwhile, a native predator,

R. pumila was found and proved to be more effective than *R. cardinalis* because it was better adapted to the climatic conditions in Taiwan. The native species always appears early in the season and disperses earlier than the introduced species.

Armored Scales: There are 15 species of armored scales attacking citrus in Taiwan of which *Chrysomphalus ficus*, *Lepidosaphes beckii*, *Parlatoria pergandei* and *P. zizyphi* are the most destructive species. *Aphytis holoxanthus* is a promising parasitoid of *C. ficus*. Tao (1974) considered that it usually played an important role in the control of *C. ficus* in Taiwan. This species was introduced directly from Hong Kong to Israel in 1956 where it quickly demonstrated a definite capacity to control the Florida red scale, *Chrysomphalus aonidum*. Stocks of this species were obtained from Israel in 1959 for colonization in Florida and Texas. It was also released in Mexico in 1961. Muma (1959) considered that the Florida red scale was brought under satisfactory natural control by *A. holoxanthus*. An effective native parasitoid of *L. beckii* is *Aphytis lepidosaphes*. The female of this species has the habit of puncturing the scale and feeding extensively on the body fluids. This habit caused high mortality in addition to that caused by parasitization. Thus, *L. beckii* is now rated as a miner or occasional pest of citrus in Taiwan. This parasitoid was introduced into California from south China and Taiwan (Flanders, 1950). It was reported to have cleaned up scale infestations at the original release sites and spread seventy miles away within 4 years. *Aphytis chrysomphali* and *Aphytis proclia* are parasitoids of *Parlatoria zizyphi*. *Aspidiotiphagus citrinus* was identified as a common parasitoid of *Aspidiotus destructor*, and occasionally parasitized in *Lepidosaphes beckii* and *Parlatoria zizyphi*. *Aspidiotiphagus lounsburyi* was found to be localized in checking *Chrysomphalus ficus*. Several parasitic fungi were found, but *Fusarium coccophilum* is the most common pathogen of *L. beckii* and *Parlatoria zizyphi* during the wet season. Predators, such as *Telsimia nitida*, *Chrysopa boninensis* and a predaceous mite, *Hemisarcoptes* sp., are not very effective biological control agents against armored scales.

Mealybugs: *Nipaecoccus filamentosus*, and *Planococcus citri* are the common citrus pests, especially the former. The introduced ladybird beetle, *Cryptolaemus montrouzieri*, is an effective predator because of its voracious appetite, but it is not active during the hot summer months. For mass rearing and field release of *Cryptolaemus* beetle, *Planococcus citri* mass reared on pumpkins was used as food. One ripe pumpkin, about 12×19 cm, per tray was sufficient to rear mealybugs to produce nearly 5,000 egg sacs. A total of 15-20 *Cryptolaemus* adults were then introduced on the pumpkins for oviposition. By this method, it is estimated that about 250 *Cryptolaemus* adults can be obtained from one pumpkin per month. A native encyrtid wasp, *Anagyrus sawadai*, was found to parasitize mealybugs. It was more resistant to hot weather conditions than *C. montrouzieri*.

Spiny Blackfly: The spiny blackfly, *Aleurocanthus spiniferus*, has been recognized as one of the minor pest of citrus in Taiwan, but it can also cause the reduction of citrus yield when its population is high. The following study, aimed at understanding the life history and biological characteristics of this blackfly, was made in order to develop a biological control program.

Surveys on spiny blackfly population was conducted at 2-week intervals in 4 citrus orchards in Wanfeng (Taichung), Kuansi (Hsinchu), Cholan (Miaoli) and Wanchiao (Chiayi) during October, 1981 to July, 1984. All sampling trees were not sprayed with insecticides. Results of this study revealed that the average number of nymphs per leaf among the 4 orchards ranged from 1.1–23.0, 0–0.9, 0–1.0, and 0–0.7, respectively.

Six generations of the spiny blackfly were recorded in a year from November, 1983 through

November, 1984 at Taichung. Potted citrus seedlings covered with cylindrical glass cage (30×15 cm) were used for blackfly oviposition. Twenty, 40 and 80 pairs of adult flies (with 5 replications) were caged per cylinder, respectively. Results revealed that fecundity of the blackfly was closely related to its population density. The number of eggs laid per female in the 40-pair treatment was the highest with an average of 19.6 ± 3.0 (cf. 20-pair treatment, 8.2 ± 2.3 ; and 80-pair treatment, 12.5 ± 2.9). The time required for the completion of one life cycle during March to May and during May to July, 1984, averaged 65.7 ± 3.8 and 49.9 ± 9.2 days, respectively. The survival rates from egg to adult averaged 20.9 ± 9 and $35.2 \pm 7.7\%$, respectively.

Three natural enemies of this blackfly were recorded; one predaceous drosophilid, *Acletoxenus* sp., and two parasitic wasps, *Prospaltella smithi* Silv., and *Amitus hesperidum* Silv. However, they all occurred at very low densities. Several entomogenous fungi infecting this blackfly were found in wet season, among which were *Aschersonia* spp., and *Aegerita webbneri* Fawc.

Sampling records from Kentou orchards where insecticides were used frequently indicated that natural enemies of the spiny blackfly were almost completely eliminated by chemicals and often resulting in outbreaks of the blackfly. During outbreaks, the number of nymphs per leaf averaged 48. In general, the natural enemies of the blackfly in citrus orchards in Taiwan are sufficient to suppress the blackfly population to a level where acceptable degree of control is obtained. The overuse of insecticides in citrus groves can kill natural enemies so that outbreaks of the blackfly are induced.

Aphids: Aphids in subtropical countries apparently reproduce all year round. The loss caused by aphid transmitted virus diseases is much greater than that by direct feeding. The citrus aphid, *Toxoptera citricidus*, is the most serious pest attacking citrus seedlings before and after grafting and nonfruiting and fruiting trees. This aphid produces substances poisonous to most predaceous species of ladybird beetles and all species of aphid-lion, but the poison does not effect most species of hover flies. The citrus green aphid, *Aphis citricola*, has become a severe pest since the use of modern insecticides. It is present in the leaf curls and cannot be controlled unless systemic insecticides are used. The cotton aphid, *Aphis gossypii*, and the tea aphid, *Toxoptera aurantii*, are also major pests of citrus.

The parasitoid, *Trioxys communis*, has been recognized as the most effective natural enemy against the cotton aphid. It was introduced into the United States in 1968. The coccinellids, *Lemnia swinhoei* and *Menochilus sexmaculatus*, are considered to be the most effective predators that regulate aphid population in Taiwan. The effectiveness of native hover flies is uncertain due to the different species occurring in different seasons, while the predaceous activity of the native aphid-lion is inferior to that of coccinellids, and hover flies. Consequently, the use of native predators and parasitoids for biological control of citrus aphids in Taiwan does not seem very hopeful.

Citrus Psylla: The citrus psyllid, *Diaphorina citri*, is an important citrus pest widely distributed in southern Asia. It has been recognized as the vector of a mycoplasma-like pathogen of the citrus, likubin, in Taiwan and mainland China. Two local encyrtids, *Diaphorencyrtus aligarhensis*, and *Psyllaephagus* sp., were recorded as parasitoids of citrus psylla in Taiwan; the former, being more active than the latter in winter months.

Through literature review and foreign correspondence, the eulophid, *Tetrastichus radiatus*, an ecto-parasitoid of *D. citri*, was found and introduced from Reunion Island with the help of Dr. R. Aubert. The first shipment was received in February, 1984. After rearing and propagating in the quarantine laboratory, a total of 180 adult parasitoids were released 4 times in the citrus orchards at Wufeng, Taichung. About one week after the field release made on June 21, 1984, a number of

mummified nymphs of *D. citri* was discovered on leaves of the released tree. But no *T. radiatus* has been discovered since then. Unfortunately, further rearing and releasing of this parasitoid was not possible because of the hot weather. Although the degree of parasitism by *T. radiatus* was variable under laboratory conditions, it sometimes reached as high as 94%.

Stinkbugs: Seven species of stinkbugs attacking citrus were recorded. The citrus green stinkbug, *Rhynchoscoris humeralis*, is considered to be the major pest. Both adults and nymphs feed on young fruits and induce fruit dropping. The egg parasitoids, *Anastatus formosanus*, *Anastatus* sp., *Trissolcus* sp., and *Tetrastichus* sp. were recorded. *A. formosanus* and *Anastatus* sp. are very effective and abundant in the later part of the citrus growing season.

Citrus Dogs: There are eight species of citrus dogs that devour new foliage, especially that of the species, *Princeps demoleus libanius*. These pests are not easily controlled with insecticides. However, the egg parasitoids, *Telenomus* sp. (Scelionidae), and *Trichogramma chilonis* (Trichogrammatidae), are very effective in checking the population of citrus dogs at any time of their occurrence. *T. chilonis* is the easiest one to propagate and release. *Telenomus* sp. is most effective in the spring and *T. chilonis*, in summer.

Citrus Leaf Miner: *Phyllocnistis citrella* is the most injurious citrus pest in nurseries and in orchards with the nonfruiting trees. Three parasitoids, *Ageniaspis citricola*, *Cirrospilus ingennus* and *Tetrastichus* sp., were able to suppress the population of this leaf miner below the economic injury level in autumn, but not in spring and summer. To control this pest, *A. citricola* was mass-produced in the greenhouse on young citrus, and then released in citrus orchards. Field colonization of this species is now in progress.

Citrus Red Mites: Several species of mites in the families Tetranychidae and Eriophyidae are serious pests of citrus in various parts of the world. More than 20 species of natural enemies of red mites have been recorded; *Stethorus loi*, *Oligota oviformis*, *Scolothrips sexmaculatus*, *Chrysopa boninensis*, *Amblyseius herbicolus*, *A. ovalis* and *A. longispinosus*, are the dominant ones. The infestation of citrus red mite, *Panonychus citri*, is becoming rather severe in citrus orchards because its predators were destroyed by the extensive and frequent use of insecticides. Because of the increasing seriousness of the mite problem and the difficulties in attaining satisfactory insecticidal control, the search for effective natural enemies is being pressed assiduously.

Citrus Rust Mite: The citrus rust mite, *Phyllocoptura oleivora*, is one of the important mite pests in Taiwan. It usually occurs in April and May. Infestation on citrus fruit resulted in mottled harvested fruits and stunted young fruits. Recently, it was found commonly infected by a fungus, *Hirsutella thompsonii* Fish., which was isolated from diseased mites last year. It was then successively cultured on potato dextrose agar medium. Suspensions of the mycelia were sprayed in the orchard in order to evaluate its pathogenicity and effectiveness against the rust mite. One week after application, the percentage of infected mites on treated trees averaged 29.6 to 51.5% in 3 concentrations (1%, 5% and 10%) of mycelia suspension, whereas the untreated trees averaged 4.4%. However, the percentage of the diseased mites on the treated trees did not increase 2 to 4 weeks after application.

In the meantime, a commercial product of the same fungus was obtained from Dr. McCoy at the University of Florida. The effectiveness of the commercial strain of *H. thompsonii* will be tested in Taiwan and be compared with our native strain.