BIOLOGICAL CONTROL OF CITRUS PESTS IN TAIWAN

By

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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

		Pest status		
Common name	Scientific name	Major	Occasional	Minor
Soft scales	Ceroplastes rubens	Andrew Prince Control of the Control		v
3011 301103	Coccus hesperidum			V
	C. viridis	v		
	Pulvinaria polygonata	A STATE OF THE	a . P	V
	Saissetia coffeae			V
	Suisseila coffede			
Otas de la conta	Icerya purchasi			V
Fluted scale	Icerya purchasi			
A www.awad.comlan	Aonidiella citrina			V
Armored scales	Aspidiotus destructor			v
		v		
5,460	Chrysomphalus ficus	v	V Ci	4.86
7.47	Lepidosaphes beckii	*7	V	
	Parlatoria pergandei	V	37	;
8 1	P. zizyphi		V	- 77
		***		. AP 4
Mealybugs	Nipaecoccus filamentosus	V		29 82
	Planococcus citri	V		14 565\$ -1345
	William Control of the Control of th			. (5514 =
White flies	Aleurocanthus spiniferus	V		
	Bemisia giffardi			V
e de la				
Aphids	Aphis gossypii	V		Ł
Proces	Aphis citricola	V		
	Myzus persicae		V	
	Toxoptera aurantii			V
	T. citricidus		V	
	1. Citricians			
Citrus psylla	Diaphorina citri	v		
Sain Islaman	Nezara viridula		v	
Stinkbugs	Pendulinus nicobarensis		v	
		v	•	
	Rhynchocoris humeralis	*		
Thrip	Thrips hawaiiensis		v	
	ten in Str	v		
Fruit fly	Dacus dorsalis	¥		
·	4.3		V	
Beetles	Adoretus formosanus	*	v	
	Anomala expansa	v	*	
	Anoplophora maculata	¥	V	
	Hypomeces squamosus		¥	
	Fe 192			V
Butterflies	Papilio bianor kotoensis	v		•
	Princeps demoleus	¥		
Mach	Adoxophyes fasciata			V
Moths	Alcis acaciarica			V
			V	
	Cania bilinea		v	
	Clania preyeri		v	
	Crytoethelca minuscula		v	
	Homona menciana		v	
	Nagadopsis shirakiana		¥	v
	Notolopharus australis postici	U3		*

各的2种设备。 (

Table 1. continued

Common name			Pest status		
	Scientific name	Major	Occasional	Minor	
	Orthocraspeda trima		v		
	Parasa consocia		V		
	Pasychira mendosa			V	
	Phyllocnistis citrella	V			
	Porthesia taiwana			V	
	Tiracola plagiata			V	
Mites	Brevipalpus obovatus		V		
	Panonychus citri	V			
	Phyllocoptruta oleivora	V			
Snails	Achatina fulica		V		
新水平线。 模	Bradybaena similaris		V		
Slug	Limacella agrestisuavians		V		

Table 2. Citrus pests and their natural enemies in Taiwan

	Pest	Natural enemy	Kind of natural enemy ¹	Frequency of occurrence
Soft scales	Coccus viridis	Aneristus cerphastae	pa	common
		Coccophagus tibialis	,,	"
		Microterys speciosus	"	,,
	Pulvinaria polygonata	Aneristus cerophastae	,,	,,
		Coccophagus tibialis	,,	
	Saissetia coffeae	Aneristus ceroplastae	"	localized
		Coccophagus tibialis	"	"
		Microterys speciosus	"	"
Fluted scale	Icerya purchasi	Cryptochaetum iceryae	pr	rare
. 14104 50410	200. y a p a a a a a a	Rodolia cardinalis	"	common
		R. pumila	"	"
Armored scales	Aonidiella citrina	Prospaltella perniciosi	pa	common
		Telsimia nitida	pr	,,
	Aspidiotus destructor	Aphytis holoxanthus	pa	,,
	,	Aspidiotiphagus citrinus	,,	,,
	Chrysomphalus ficus	Aphytis holoxanthus	"	"
		Aspidiotiphagus lounsburyi	"	localized
		Chrysopa boninensis	pr	commor
		Cybocephalus gibbulus	**	localized
		Hemisarcoptes sp.	"	rare
		Pharoscymnus taoi	"	localized
		Telsimia nitida	"	commor
	Lepidosaphes beckii	Aphytis holoxanthus	pa	localized
		A. lepidosaphes	,,	.,
		Aspidiotiphagus citrinus	,,	41
		Chrysopa boninensis	pr	commor

Table 2. continued

Telsimia nitida "Aspidiotiphagus citrinus pa Fusarium coccophilum f loc Chrysopa boninensis pr con Hemisarcoptes sp. "Talsimia nitida "Aspidiotiphagus citrinus pr con Hemisarcoptes sp. "Talsimia nitida "Aspidiotiphagus citrinus "Fusarium coccophilum f Hypocrella aleyrodis "Ophinoectria tetraspora "Talsimia nitida "S. coccophila "S. coccophila "S. coccophila "S. coccophila "Talsimia nitida niti		Pest	Natural enemy	Kind of natural enemy ¹	Frequency of occurrence
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Table 2. continued

	Pest	Natural enemy	Kind of natural enemy	Frequency of occurrence
		Propylaea japonica	pr	common
		Pseudaspidimerus japonensis	"	localized
		Scymnus frontalis	"	common
		quadripustulatus		
Psylla	Diaphorina citri	Diaphorencyrtus aligarhensis	pa	common
	•	Psyllaephagus sp.	**	localized
		Chrysopa boninensis	pr	"
Stinkbug	Rhynchocoris humeralis	Anastatus formosanus	pa	common
		Tetrastichus sp.	"	localized
Fruit fly	Dacus dorsalis	Opius arisanus	pa	localized
	20000 0000000	O. flecheri	"	**
		O. formosanus	"	"
		O. makii	,,	"
Butterfly	Princeps demoleus	Trichogramma chilonis	pa	common
Moths	Phyllocnistis citrella	Ageniaspis citricola	pa	common
		Cirrospilus ingennus	"	
		Tetrastichus sp.	"	localized
	Porthesia taiwana	Apanteles sp.	,,	,,
		Ichneumonid wasp	•	
Mites	Panonychus citri	Amblyseius herbicolus	pr	common
\$ To		Arthrocnodax occidentalis	,,	localized
Delina .		Chrysopa boninensis	**	
part of the second		Oligota oviformis	,,	common
44(E65 .		Stethorus loi		"
in gift	Phyllocoptruta oleivora	Hirsutella thompsonii	f	

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 Sclaes: 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 Paratoria 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 cylindric glass cage $(30 \times 15 \text{ cm})$ 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 $35.2\pm7.7\%$, 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 aphidlion 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%.

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Stinkbugs: Seven species of stinkbugs attacking citrus were recorded. The citrus green stinkbug, Rhynchocoris 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, Citrospilus 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, Amblyseisus 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, Phyllocoptruta 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.