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A REVIEW OF THE BIOLOGICAL CONTROL OF CROP PESTS IN TAIWAN

(1981—1984)

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(1981–1984)

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

Table 1. continued

Common name	Scientific name	Pest status		
		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	
	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
		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	common
		Cybocephalus gibbulus	"	localized
		Hemisarcoptes sp.	"	rare
		Pharoscymnus taoi	"	localized
		Telsimia nitida	"	common
	Lepidosaphes beckii	*Aphytis holoxanthus*	pa	localized
		A. lepidosaphes	"	"
		Aspidiotiphagus citrinus	"	"
		Chrysopa boninensis	pr	common

Table 2. continued

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

Table 2. continued

Pest		Natural enemy	Kind of natural enemy[1]	Frequency of occurrence
		Propylaea japonica	pr	common
		Pseudaspidimerus japonensis	"	localized
		Scymnus frontalis quadripustulatus	"	common
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
		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
		Arthrocnodax occidentalis	"	localized
		Chrysopa boninensis	"	"
		Oligota oviformis	"	common
		Stethorus loi	"	"
	Phyllocoptruta oleivora	*Hirsutella thompsonii*	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 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 (30×15 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±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, *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, 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, 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.

SURVEY OF THE NATURAL ENEMIES OF THE LAC INSECT, *KERRIA LACCA*, IN TAIWAN

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The lac insect [*Kerria lacca* (Kerr)] was introduced purposely into Taiwan from Thailand around 1940 for commercial shellac production. At that time it was a promising enterprise. However, after World War II, due to the development of synthetic shellac, there was no demand for the natural product. The lac insects, not properly managed, then escaped and became an important orchard pest of litchi, sugar apple, longan, and other fruits.

Although this pest can be effectively controlled by dimethoate, azodrin, antio and sumithion during the nymphal stages, it cannot be controlled in the adult stage because it secretes a thick wax layer over its body. Furthermore, it is difficult to spray when the trees are tall and planted in mountain areas. Therefore, biological control appears to be the best method of control.

METHOD OF STUDY

Samples of lac insect infested branches of host plants were collected two or three times per month. They were kept in laboratory until the emergence of parasitoids. The emerged parasitoids were prepared as dry specimens and preserved for identification and further study. Samples were collected from the northern part of Taiwan and the Pingtung areas of southern Taiwan during August to September 1981. In addition, general surveys of the natural enemies of the lac insect were conducted in Taichung, Nantou, Changhua, Chiayi, Kaohsiung and Pingtung from September 1981 until June 1982.

RESULTS

The results of surveys conducted during August 1981 to May 1982 in northern Taiwan are given in Table 1. The total number of parasitoids obtained from the whole survey was over 550. Because the identification of the parasitic insects are not yet complete, the species obtained are not reported in this paper. However, from Table 1 it is apparent that the ubiquitous banyan tree (*Ficus retusa*) is the most favorite host plant of the lac insect. This tree is also the preferred habitat of the natural enemies of the lac insect.

Table 1. Summary of survey data of lac insect obtained in northern Taiwan during 1981–1982 (NTU)

Locality	Date	Host plant	Parasitoid emergence
Taipei	11 Aug. 1981	*Albizzia* sp.	+
		Ficus retusa	++
Mucha	20 Aug. 1981	"	++
Sanshia	22 Aug. 1981	"	+
		Mangifera indica	+
Mucha	28 Aug. 1981	*Ficus retusa*	+
		Mangifera indica	++
Shintien	28 Aug. 1981	*Ficus retusa*	+
		Euphoria longana	+
Taipei	5 Sep. 1981	*Ficus retusa*	+
Hsichih	8 Sep. 1981	"	+
Shintien	11 Sep. 1981	"	+
		Euphoria longana	+
Chuwei	24 Sep. 1981	*Ficus retusa*	+
Panchiao	28 Sep. 1981	"	+
Shintien	12 Oct. 1981	"	+
Panchiao	14 Oct. 1981	"	++
Mucha	2 Nov. 1981	"	+
Neihu	18 Nov. 1981	"	+
Shintien	7 Mar. 1982	"	++
Kueishan	11 Mar. 1982	"	+
Shinchung	24 Mar. 1982	"	+
Panchiao	6 Apr. 1982	"	+
Nunshuchia	19 Apr. 1982	"	+
Taishan	29 Apr. 1982	"	++
Shintien	11 May 1982	"	++
Shengkeng	25 May 1982	"	+

From the samples taken from Taichung, Nantou, Changhua, Chiayi, Kaohsiung and Pingtung, a total of five parasitoids were obtained. They were *Eupelmus tachardiae* (Eupelmidae), *Parechthrodyinus* sp., *Tachardiaephagus* sp., and *T. tachardiae* (Encyrtidae), and *Tetrastichus purpureus* (Eulophidae). In addition to the parasitoids, five predators were obtained. They were *Chrysopa* sp. (Chrysopidae), *Eublemma conspersa* and *E. roseonivea* (Noctuidae), *Telsimia chujoi* (Coccinellidae), and an oligotomid. The densities of those natural enemies are given in Table 2. It was observed that none of those parasitoids and predators were controlling the lac insects. The *T. tachardiae* was only recorded in southern Taiwan (Kaohsiung and Pingtung) by Chiu *et al.* (1981), but was first recorded in central Taiwan (Yuanlin, Changhua) in this study.

Table 2. Numbers of natural enemies reared from lac stick per meter from Takangshan, Kaohsiung (TARI)

Natural enemies	Month									
	1981				1982					
	9	10	11	12	1	2	3	4	5	6
Eupelmus tachardiae	0	0	0	0.05	0	0	0	0	0	0.3
Parechthrodyinus sp.	0.04	0.2	0	0	0	0	0	0	0	0
Tachardiaephagus sp.	0	0	0	0.2	0	0.03	0	0.02	0	0
T. tachardiae	0	6.2	7.0	18.3	0	0	0	0.05	10.1	0
Tetrastichus purpureus	0.3	12.6	2.4	0.8	0.3	1.0	10.5	30.5	23.2	25.3
Chrysopa sp.	0	0.1	0.2	0.1	0.1	0.07	0.1	0	0	0
Eublemma conspersa	0.2	0.3	0.2	0.1	0	0	0.05	0.2	0.1	0.3
Eublemma roseonivea	0.1	0.3	0.7	0.6	0	0	0	0	0.6	0.5
Telsimia chujoi	0	0.06	0	0	0	0	0	0	0	0

DISCUSSION

Preliminary data obtained from northern Taiwan indicated host tree preference by the lac insect and its natural enemies. Further studies are needed because it is possible that biological control of this pest may be successful on certain trees but not in others.

Two predators, *E. amabilis* and *Holcocera pulverea*, were reported to destroy 35 per cent of the lac insect population in India. However, because these two species are lepidopterous insects, which are generally plant feeders, the hazards of their importation into Taiwan should be by given serious consideration.

This study showed that there are five species of parasitoids and predators that attack the lac insect. None of these species can be considered effective. Efforts should be made to locate related species in other parts of the world and to import them into Taiwan.

IMPORTATION AND ESTABLISHMENT OF *TETRASTICHUS BRONTISPAE*, A PARASITOID OF THE COCONUT BEETLE, IN TAIWAN

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The coconut palm, *Cocos nucifera* Linn. is grown in the tropical and subtropical regions of the world. In Taiwan, it can be found on the east coast and in areas south of Taichung. The number of coconut trees planted in 1960 was estimated to be about 12,000 trees, but it was gradually increased to a total of about 600,000 trees. The trees were planted along highways and around fish ponds.

The coconut beetle, *Brontispa longissima* Gestro, a serious pest of the coconut palm, was first found in Pingtung in July, 1975. Since then, it has spread north- and eastward to Hualien and Taitung. Because coconut trees are tall and planted mostly around fish ponds, it is unsuitable for chemical control because of the danger to fish. Therefore, the biological control approach of this pest is the most practical one.

A number of parasitoids of *Brontispa* beetle are known to occur in Austro-Malayan Region, however, only the larval and pupal parasitoid, *Tetrastichus brontispae* (Ferriere) has been widely used for biological control in the Pacific Region. In Indonesia, for example 60-90% parasitism was recorded.

The first and second shipments of *T. brontispae* were received on 3rd and 5th of November in 1983 through the cooperative efforts of Dr. R. Muniappan, University of Guam. The parasitoids from these two shipments were held in the quarantine laboratory at TARI upon arrival. About 2 weeks later, numerous adults emerged. Since then, the subsequent propagation of this parasitoid was carried out without any problems.

Field releases of *T. brontispae* were made at Chenchinhu (Kaohsiung) and Linbien (Pingtung). Ten releases of 11,456 adults were released at Chenchinhu in January-November, 1984, and 7 releases of 4,881 adults were released at Linbien in February-November, 1984. The percent parasitism recorded from Chenchinhu and Linbien averaged 21.2-79.9% and 9.3-63.4%, respectively (Table 1).

Table 1. Percentage of pupal parasitism by *T. brontispae* on *B. longissima* at releasing sites (1984)

Month	% of pupal parasitism	
	Chenchinhu	Linbien
Feb.	21.2	9.3
Mar.	78.1	17.6
Apr.	49.5	22.5
May	61.1	36.2
Jun.	79.2	46.6
Aug.	26.4	63.4
Nov.	79.9	58.0

In cooperation with the National Pingtung Agricultural Institute, the studies on field populations of *B. longissima* on the coconut palm prior to, or after parasitoid releases were investigated regularly at the released sites of Kaohsiung and Pingtung. Results showed that the population density of the coconut beetle on the released trees are greatly decreased in Chenchinhu and less in Linbien. However, it is evidently that the introduced parasitoid has already established in this island and hence to perform as a good biological control agent of the coconut beetle in Taiwan.

PRELIMINARY STUDIES ON BIOLOGICAL CONTROL OF THE MULBERRY PSYLLID

By
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This is a brief summary of the studies on biological control of the mulberry psyllid.

Twelve species (*Menochilus sexmaculatus, Coelophora chinensis, Coccinella octomaculata, Coelophora circumusta, Lemnia swinhoei, Lemnia biplagiata, Leis dimidiata, Propylaea japonica, Coccinella septempunctata, Synonycha grandis, Cryptogonus horishanus, Stethorusloi saeji*) of the predacious ladybug, which fed on the mulberry psyllid, *Paurocephala psylloptera* Crawford were found in the mulberry grove at specialized sericultural areas in Taiwan. Studies were initiated to (1) determine the distribution and population density of nine more abundant species, and (2) compare the seasonal population fluctuations of four major ladybugs with those of the psyllid. The population densities of the 9 ladybug species in 4 areas are summarized in Fig. 1. All ladybug species were found to overwinter in the adult stage. *Menochilus sexmaculatus* (Fabricius) had the highest density and was present in all of the 4 areas studied. The seasonal population fluctuations are given in Fig. 2. Results showed that the population flucturations of *M. sexmaculatus* were significantly correlated to those of the mulberry psyllid.

The above results showed that *M. sexmaculatus* is definitely the key species with promise for biological control of the mulberry psyllid. Thus detail studies on its development, survival and prey consumption were conducted. The results are summarized as follows. The developmental durations of *M. sexmaculatus*, fed with green peach aphids, *Myzus persicae* (Sulzer) and mulberry psyllids, were similar, but the survival rates were higher when the ladybug was fed with the aphids (Table 1). The total amount of aphids consumed by the larval stage of *M. sexmaculatus* at 25°C was 74.7, and that of psyllid 304.2. (Table 1, 2)

In order to utilize *M. sexmaculatus* in the biological control program, further studies included (1) the development and reproduction of *M. sexmaculatus* at various temperatures, (2) the effect of *M. sexmaculatus* on the psyllid population density, (3) the population fluctuations of both the ladybug and the psyllid in insecticide treated and untreated groves, and (4) the proper timing for the chemical control of the psyllid and protection of the ladybug and the silkworm.

The results are summarized as follows. The duration of each stage and fecundity of *M. sexmaculatus* at 3 temperatures were listed in Table 3. The intrinsic rate of increase (r being 0.105, 0.165, 0.248, respectively), mean generation time (T being 51.97, 30.07, 19.52 days, respectively) and net reproductive rate (R_o being 230.89, 143.92, 126.55, respectively) at 3 temperatures were computed from the life table data (Table 4).

[1]Currently Taiwan Agricultural Chemicals and Toxic Substances Research Institute.

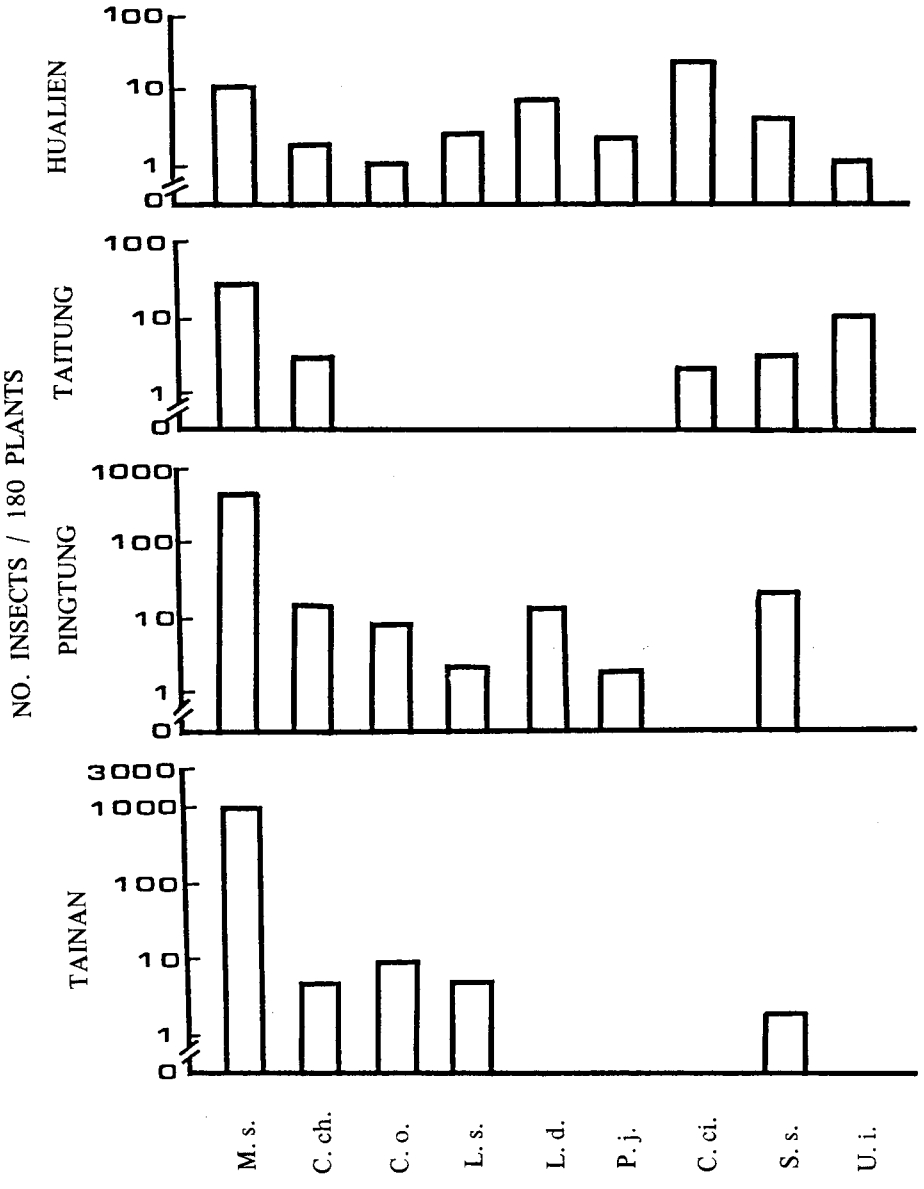


Fig. 1. Population densities of nine species of ladybugs found in the mulberry groves at Tainan, Pingtung, Taitung and Hualien, June, 1982.

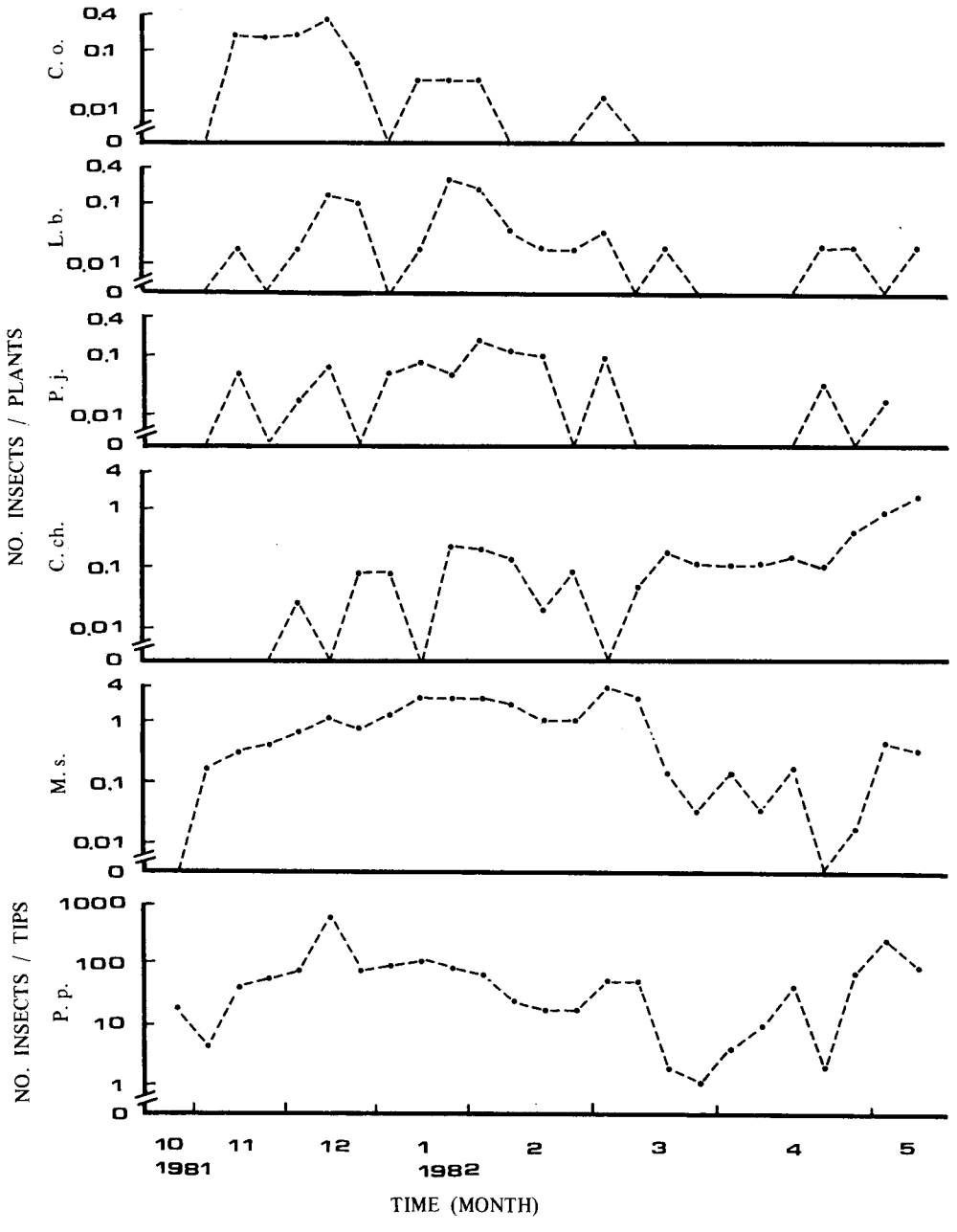


Fig. 2. Population densities of the mulberry psyllids and five species of ladybugs found in the experimental mulberry grove at Wufeng, Oct., 1981 – May, 1982.

Table 1. Developmental duration and survival rate of each stage of *Menochilus sexmaculatus* fed with mulberry psyllids or aphids in the laboratory at 18°C and 25°C, 70% r.h.

Stage	Food	°C	Duration (days) mean ± s.d.	Survival rate (%)
Egg	Psyllids	18	4	85.50
		25	2	100.00
	Aphids	18	3.76±0.44	88.10
		25	2.40±0.50	100.00
Larva 1st	Psyllids	18	2.80±0.81	94.07
		25	1.45±0.50	97.30
	Aphids	18	4.16±0.85	80.95
		25	1.80±0.62	78.57
2nd	Psyllids	18	1.70±0.65	95.93
		25	1.16±0.37	98.55
	Aphids	18	2.48±0.51	100.00
		25	1.10±0.30	93.55
3rd	Psyllids	18	2.83±1.15	90.29
		25	1.47±0.50	94.21
	Aphids	18	2.08±0.64	100.00
		25	1.25±0.44	96.15
4th	Psyllids	18	5.57±1.14	73.56
		25	2.43±0.54	77.89
	Aphids	18	4.24±0.93	96.67
		25	2.15±0.49	90.91
Pupa	Psyllids	18	6.73±1.14	46.88
		25	3.25±0.52	66.22
	Aphids	18	6.96±0.20	86.21
		25	2.65±0.49	100.00
Total	Psyllids	18	23.63±1.92	24.02
		25	11.76±0.44	46.59
	Aphids	18	23.64±1.55	59.43
		25	11.35±1.23	64.25

Table 2. Consumption of the aphids or psyllids by *Menochilus sexmaculatus* in the laboratory at 18°C and 25°C, 70% r.h.

Stage		°C	No. insects consumed/day (mean ± s.d.)	
			Aphids	Psyllids
Larva	1st	18	2.4 ± 1.7	–
		25	3.6 ± 1.5	12.4 ± 9.50
	2nd	18	3.7 ± 3.3	–
		25	7.2 ± 2.0	29.0 ±13.90
	3rd	18	8.0 ± 3.9	–
		25	12.1 ± 4.7	48.2 ±20.10
	4th	18	14.6 ± 9.1	–
		25	21.0 ± 4.0	74.8 ±26.10
Adult		18	17.4 ±10.3	–
		25	–	82.5 ±14.30

Table 3. Duration of each developmental stage and fecundity of *Menochilus sexmaculatus* at three temperatures

Stage		20°C[1]	26°C[2]	30°C[1]
Egg		3.9± 0.45	2.5 ± 0.6	1.3 ± 0.50
Larva	1st	1.7± 0.59	0.9 ± 0.2	0.8 ± 0.25
	2nd	2.4± 0.58	1.2 ± 0.48	0.9 ± 0.22
	3rd	2.8± 0.84	1.5 ± 0.61	1.1 ± 0.41
	4th	5.3± 0.97	3.2 ± 0.73	2.0 ± 0.49
Pupa		6.8± 0.39	5.1 ± 0.49	3.0 ± 0.36
Adult	Preovipositing	2.6± 0.87	1.3 ± 0.75	1.2 ± 0.56
	Ovipositing	52.8± 13.02	50.6 ± 21.57	33.6 ± 9.58
	Male longevity	80.3± 14.58	46.6 ± 20.89	39.6 ± 13.06
	Female longevity	83.1± 14.67	64.8 ± 26.38	40.5 ± 14.79
	Fecundity (No. egg/female)	540.2±225.26	549.3 ±248.01	643.0 ±329.88

[1] mean ± s.d. of 150 replicates; ladybugs fed with aphids.
[2] mean ± s.d. of 150 replicates; ladybugs fed with psyllids.

Table 4. The intrinsic rate of increase (r), net reproductive rate (R_o), and mean generation time (T) of *Menochilus sexmaculatus* at three temperatures

°C	R_o	T	r
20	230.89	51.97	0.105
26	143.92	30.07	0.165
30	126.55	19.52	0.248

In tests under greenhouse conditions, the control of the mulberry psyllid by *M. sexmaculatus* was found to be most efficient when a ratio of 1 ladybug to 200 psyllids was set up (Table 5). Field tests showed that populations of both the ladybug and the psyllid declined soon after the spray of insecticide (Fig. 3). Recovery of the population was found to be faster in the ladybug than in the psyllid. Bioassay data indicated that the residual effects of Fenthion, Heptenophos, Metasystox, and DDVP were shorter whereas Monocrotophos, Dicrotophos, and Carbofuran were longer, thus the latter should not be applied in the mulberry grove during the silkworm rearing period (Table 6).

Table 5. Efficacy of biological control of the mulberry psyllid by the ladybug in the green-house

No. of ladybug	No. of mulberry psyllid and % of control								
	before tr.	1 wk. tr.		2 wk. tr.		3 wk. tr.		4 wk. tr.	
	No.	No.	% control	No.	% control	No.	% control	No.	% control
1	135.8	46.3	62.98	30.9	74.94	8.6	92.32	1.4	98.40
	222.8	66.8	67.45	56.4	72.12	25.6	86.07	8.2	94.30
	430.2	343.9	13.20	279.2	28.52	212.0	40.27	181.0	34.36
2	125.3	10.8	90.64	3.9	96.57	0.1	99.99	0.0	100.00
	230.6	72.2	66.00	31.8	84.81	32.4	82.97	11.9	91.95
	426.1	147.7	62.36	82.5	78.68	29.1	91.72	7.1	97.40
	838.2	708.6	8.21	596.7	21.60	607.8	12.11	537.2	1.60
4	147.3	2.3	98.30	0.0	100.00	0.0	100.00	0.0	100.00
	419.3	95.4	75.31	36.0	90.55	21.0	93.93	0.0	100.00
	842.7	357.2	53.98	302.8	60.43	167.4	75.92	89.1	83.51
	1273.5	897.4	23.49	756.1	34.61	776.4	26.10	509.3	37.61
6	127.9	0.8	99.32	0.0	100.00	0.0	100.00	0.0	100.00
	641.3	250.8	57.54	23.4	95.98	0.0	100.00	0.0	100.00
	1263.8	889.6	23.57	357.3	68.66	203.4	80.49	164.7	79.67
	1882.8	1078.3	37.82	834.2	51.20	609.3	60.77	537.4	55.47
CK	223.9	206.2	0.00	203.4	0.00	184.8	0.00	143.6	0.00

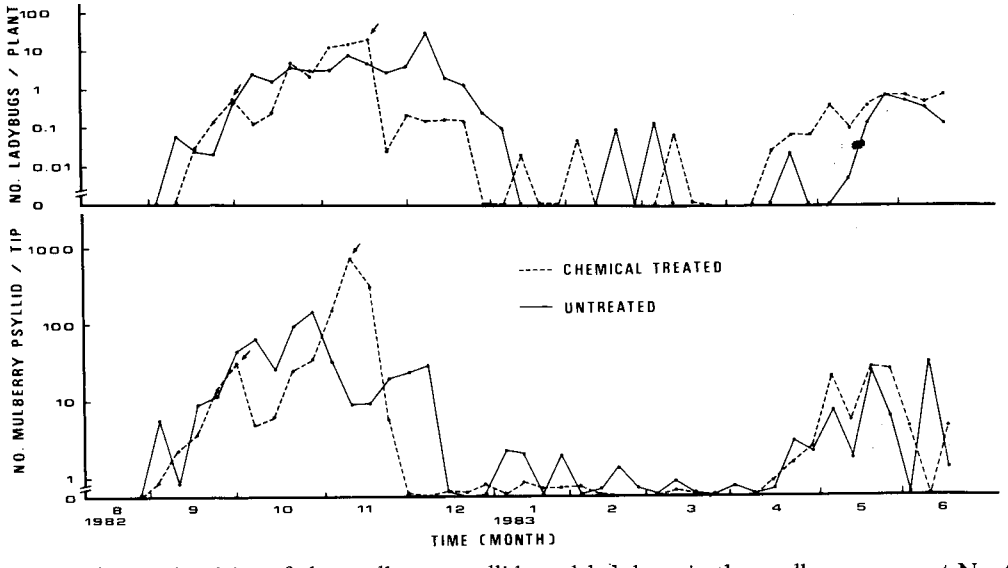


Fig. 3. Population densities of the mulberry psyllids and ladybugs in the mulberry grove at Nantou.

Table 6. Bioassay of the chemical residual effects on the silkworm larvae fed with treated mulberry leaves

Insecticide	ppm	Mortality (%) after treatment			
		10 days	15 days	20 days	25 days
		3rd Instar			
Monocrotophos	500	55	83.3	0	0
	375	53.3	85	0	0
	250	41.7	0	0	0
Dicrotophos	500	6.9	0	0	0
	375	3.3	0	0	0
	250	1.7	0	0	0
Carbofuran	500	45	36.7	5	3.3
	375	10	3.3	5	0
	250	15	3.3	1.7	0
CK		0	0	0	0
		4th Instar			
Monocrotophos	500	96.33	90.0	51	0
	375	92.7	81.7	50	0
	250	48.3	8.0	0	0
Dicrotophos	500	6.7	1.7	0	0
	375	1.7	0	0	0
	250	1.7	0	0	0
Carbofuran	500	68.3	33.3	20	3.3
	375	36.7	6.7	3.3	1.7
	250	28.3	0	1.7	0
CK		0	0	0	0
		5th Instar			
Monocrotophos	500	100	86.7	48.3	66.7
	375	100	78.3	35	36.7
	250	100	23.3	8.3	1.7
Dicrotophos	500	100	0	0	0
	375	96.7	0	0	0
	250	56.7	0	0	0
Carbofuran	500	100	41.7	21.7	1.7
	375	100	35	5	1.7
	250	98.3	11.7	3.3	0
CK		0	0	0	0

BIOLOGICAL CONTROL OF MULBERRY SPIDER MITES, *TETRANYCHUS KANZAWAI*, WITH AUGMENTATION OF *AMBLYSEIUS WOMERSLEYI*

By
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Tetranychus kanzawai was one of the most polyphagous and notorious spider mites occurring in most of crop systems in Taiwan and far east Asia. Among the crop systems, economic injury caused by kanzawa spider mites was found mainly in mulberry, pear, tea, strawberry, carambola, and papaya through discoloration and wilting and dropping of leaves and fruits. Failure to control the kanzawa spider mites through chemical application necessitated the development of biological control and integrated control strategies in Taiwan.

According to the literature, spider mites have no parasitoid but have many predatory insects and mites. There are limited reports on successful manipulation of them. But predatory mites of *Phytoseiulus, Typhlodromus*, and *Amblyseius* mites have been mass reared and released mostly in orchards and strawberry in temperate area (Oatman 1965, Hoy *et al.* 1982). In Taiwan, the biology of two indigenous species, *Amblyseius womersleyi* and *Amblyseius ovalis* and their control of a kanzawa spider mite were conducted during the past five years (unpublished data). The mass rearing technique and release ratio of the predator to the spider mites and processes of *A. womersleyi* were developed for the mulberry field releases. The results were evaluated on the basis of the population density of spider mite, and the value and cost/benefit of silkworm cocoon production from the field.

PREDACEOUS MITES SPECIES AND ITS POPULATION DENSITIES ASSOCIATED WITH *TETRANYCHUS KANZAWAI* IN TAIWAN

There are five major *Amblyseius* spp. occurring with kanzawa spider mite population in the mulberry groves. They are *Amblyseius deleoni, A. maai, A. okinowanus, A. ovalis*, and *A. womersleyi.* The seasonal population densities of kanzawa spider mites, *Eotetranychus banki* and their *Amblyseius* predators, the life history and reproduction pattern of adults of the last two species of mite predator and the kanzawa spider mite were studied by Chang (1981) and Hsu (1983). *A. womersleyi* was shown as a delay density dependent factor for *kanzawai* and *banki* spider mite population. However, the *A. womersleyi* populations were mostly dependent on the population of *T. kanzawai.* Chang (1981) also reported that both *T. kanzawai* and *A. womersleyi* inhabited the lower leaves. The latter occurred only when the population density of the former was high.

The data on seasonal density of both prey and predators showed that the predators, although had a high searching ability or a high reproductive rate, had little suppression effect over the spider mite population, i.e. the naturally occurring predaceous mites were not sufficient to control the spider mites. Therefore, augmentation would be needed for the biocontrol of the spider mite in the mulberry system, and mass rearing and mass release of *A. womersleyi* were attempted.

MASS REARING OF *A. WOMERSLEYI*

Phaseolus vulgaris was selected as the host plant of spider mite after testing more than 70 host plant species. The process and techniques of host-plant planting, spider mite rearing, and colony conservation and mass rearing of *A. womersleyi* were illustrated in Fig. 1.

DAMAGE THRESHOLD AND CONTROL THRESHOLD OF SPIDER MITE DENSITY

Changes in color of mulberry leaves due to spider mite feeding were determined on potted mulberry trees. The leaves were fed to silkworm larvae to evaluate the damage threshold of spider mites. The leaf-color differences by National Bureau of Standard (NBS) and the weight of the 1st instar of silkworm larva had a positive and a negative natural logarithmic linear correlation with mite damage, respectively (Fig. 2 & 3). Five percent of larval weight loss was arbitrarily assumed for damage threshold of spider mites on mulberry. The damage threshold was hypothetically estimated at 0.42 mite-day/cm^2 which was equivalent to 9.24 mite-day/leaf at an average leaf area of 110 cm^2 for 5-day injury duration [(1.42-1) mite-day/cm^2 x (110 cm^2/leaf ÷ 5 days)]. An upper limit of mite damage for 15-20% of larval weight loss was set for the requirement of acaricide application. An upper limit of 28.5-44.6 mite/leaf was also calculated by the same process.

COST ANALYSIS OF MASS REARING *A. WOMERSLEYI*

The cost of mass rearing the predators is determined by the cost and efficiency of labor, facilities and flow of processes. The processing flow of mass rearing of predator has been determined as shown in Fig. 1. In view of the limited amount of predator reared per labor, the utilization of facilities, and the turnover time of a cyclic transfer or inoculation of prey and predators, the batch production of 300,000 predators is considered economical. This production will cost NT$0.015 per predator (Table 1). The cost can be reduced to NT$0.01 per predator at 1,000,000 predator rearing.

PACKING AND TRANSPORTATION OF PREDATORS

Predators can be easily packed with host plants, prey and some absorbent paper strips in a PE bag. They are retained for 24-48 hrs in dark condition at room temperature. During this period, the spider mites would be either desiccated or consumed by predators, thus none would be distributed into the field. For long distance transportation the bag with predator was aeriated with a pump and put into a carton. The predators can stand this condition for 2-3 days without reduction in survival. The predators are released into the field by simply emptying the bag by hand.

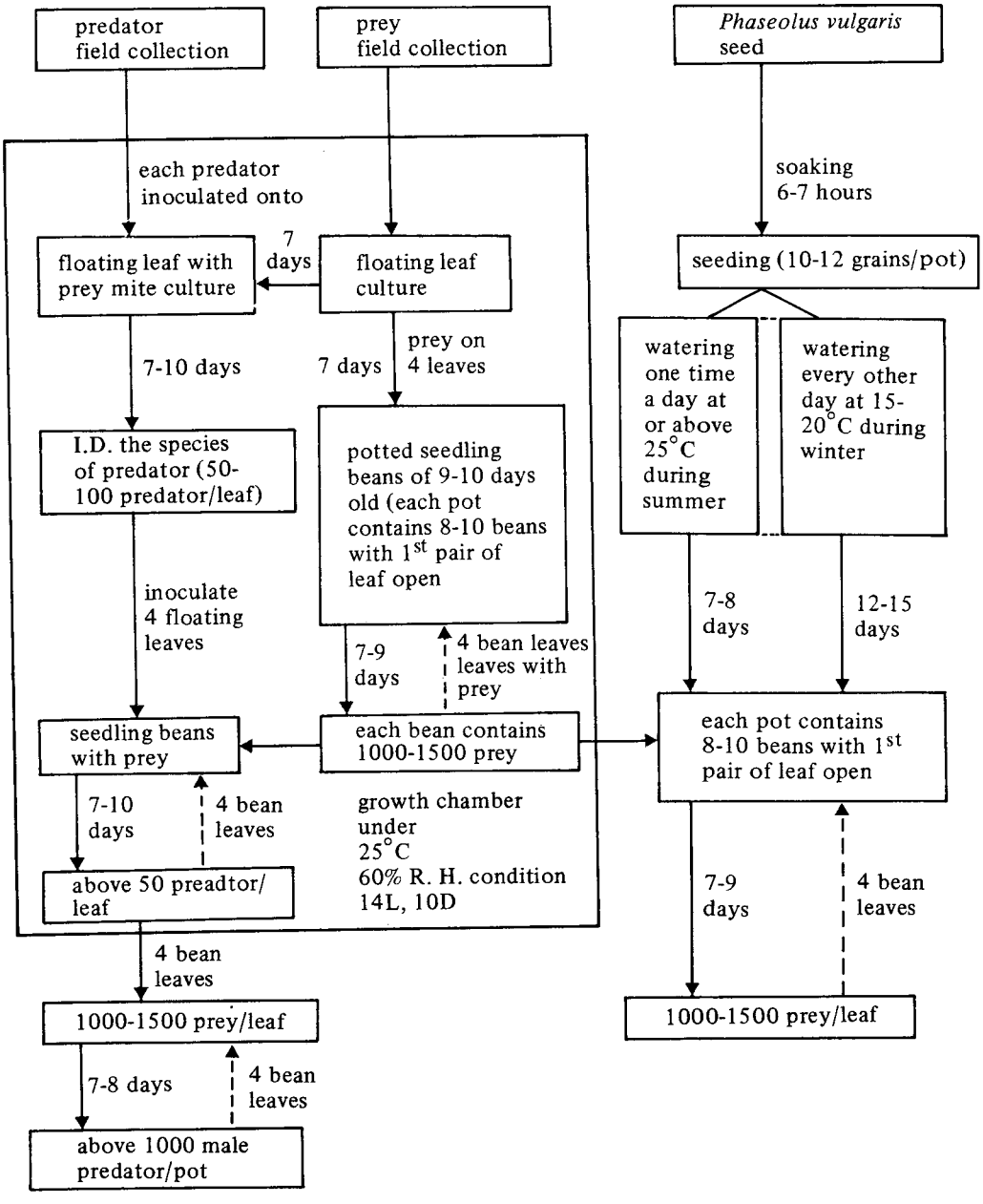


Fig. 1. Flow-chart of mass rearing of *Amblyseius womersleyi.*

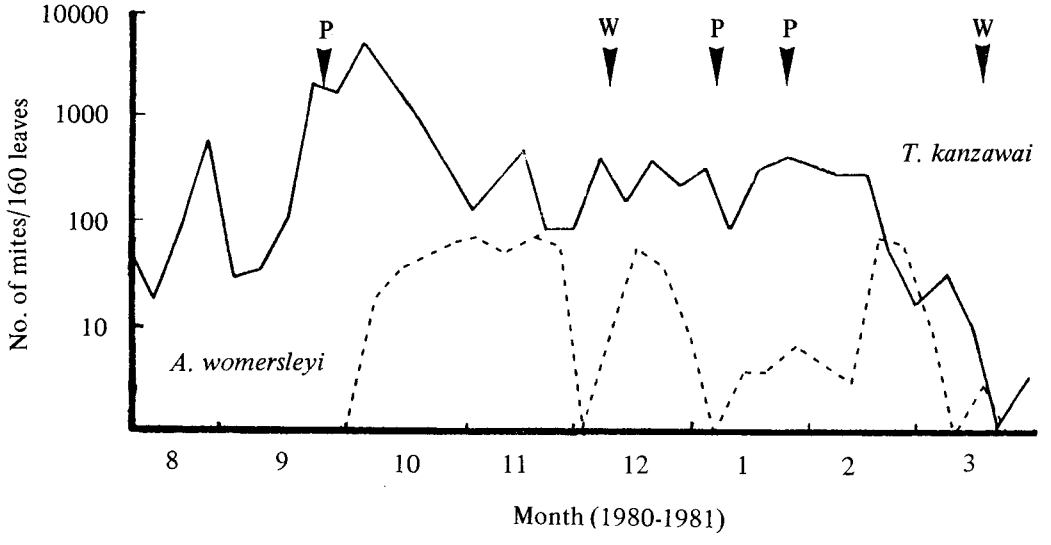


Fig. 2. Population density of *Tetranychus kanzawai* and *Amblyseius womersleyi* in mulberry grove in Taiwan, 1980-1981. (P: Prunning, W: Weeding.)

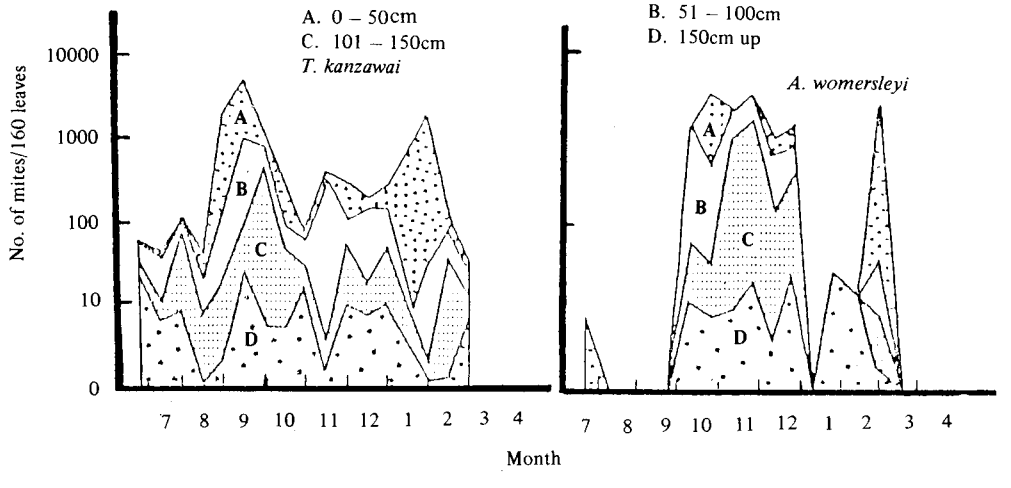


Fig. 3. Vertical distribution of population of *Tetranychus kanzawai* and its predator *Amblyseius womersleyi* on two mulberry groves in Taiwan, 1980-1981.

Table 1. Cost analyses for mass rearing of 300,000 *A. womersleyi*

Items	Cost (NT$)	Note
Labor cost	750	300,000 at 600 predators/pot = 500 pots. 500 pots at 200 pots/labor-day = 2.5 labor-day. 2.5 labor-day at $300/labor-day = $750.
Seeds	400	500 pots at 12 seeds/pot = 6,000 seeds. 6,000 seeds at 600 seeds/kg = 10 kg. 10 kg at $40/kg = $400.
Soil	940	500 pots at 0.00471 m^3/pot = 2.35 m^3. 2.35 m^3 at $400/$m^3$ = $940.
Fertilizer	250	500 pots at 100 pots/bag = 5 bags. 5 bags at $50/bag = $250.
Electricity	1,920	Two 0.08 kw lights x 12 hrs /25 pots = 0.0768 kw/day/pot. 0.0768 kw/day/pot x 25 day x 500 pots = 960 kw-hrs. 960 kw-hrs at $2 kw-hr = $1,920.
Total	4,362	

The expenses of pots, rearing facilities, predator colony maintenance, and miscellaneous items were not in the analysis.

COMPARISON OF COST OF SPIDER MITE CONTROL WITH PREDATOR RELEASE AND ACARICIDE APPLICATIONS

At population density of 5 spider mites per leaf in mulberry field, the biocontrol with *A. womersleyi* and acaricide applications were conducted in different groves. One release of predators (release ratio between predator and prey was 1:30) at 100,000 individuals per hectare was sufficient to control spider mite population for at least one month, and resulted in a 95 out of 100 times of success. On the other hand, chemical alternates required weekly sprays to achieve an equal suppression of spider mite population. The ratio of cost of biological and chemical control was 1 to 3 (Table 2).

EVALUATION OF MASS RELEASE OF *A. WOMERSLEYI* IN MULBERRY GROVES

Spider Mite Control with Mass Release of *A. womersleyi*: During the spring season (Mar.-Apr.) of 1983 and 1984, 100,000 predaceous mites per hectare were released into the mulberry field and a significant reduction of spider mite population was obtained in fields with initial spider mite population of less than 22 mites/leaf (Table 4). However, when initial mite population was high, the effect of releasing predators was lower, but still higher than chemical applications (Table 3). In 1984,

Table 2. Comparison of cost and benefit index between chemical control and biological control of mulberry kanzawa spider mites

Items	Expenses (per hectare)	
	Biological	Chemical
Cost of control		
Predator or chemical	$2,908	$800
Effective duration	30 days	7 days
Labor	$300	$600
Average cost/ha/day	$107 (2,908 + 300)/30	$200 (800 + 600)/7 days
Average of successful* control in 4 weeks	0.95	0.65
Actual cost per hectare per day	$112.6 (107/0.95)	$308 (200/0.65)
Economical benefit index of control**	3 (1/113 = 0.01)	1 (1/308 = 0.03)

*Results were calculated from release and nonrelease plots in which the spider mite density was reduced to 1.0 or less per leaf within 2 weeks after the treatment in 1983 and 1984.
**The economical benefit index of biological control to chemical control was 3 to 1 from the calculation of the item 4.

Table 3. Mass releases of 100,000 *Amblyseius womersleyi* per hectare against kanzawa spider mites in mulberry groves in spring of 1983

Area	Releasing date		Prereleasing density of spider mites (individuals per leaf)	Average density of mites in predator released plots (mites per leaf)[2]		Average density of mites in predator non-released plots (mites per leaf)[2]	
	Releasing day	Last sampling day		Spider mite	Predators	Spider mite	Predator
Nantou	0304	0415	17.50± 7.27	6.13± 1.17*b*	0.80±0.09*b*	15.16±1.18*a*	0.65±0.09*a*
Yuanlin[3]	0321	0419	218.03±312.35	288.67±81.62*a*	2.45±0.12*a*	348.69±5.66*b*	0
Tainan	0324	0422	21.90± 38.07	1.35± 0.94*c*	0.35±0.18*c*	7.40±6.82*c*	0.20±0.17*b*
Taitung	0322	0419	2.73± 0.67	0.40± 0.49*d*	0.13±0.13*d*	–	–
Nantou[1]	0304	0415	1.00± 0.04	7.24± 0.49*b*	0.16±0.04*d*	15.16±1.18*a*	0.65±0.09*a*

[1]Chemical sprayed plots with 25.5% chlorobenzen E.C. at 1,000 × diluting solution at 1.5 liter/ha. Chemicals were sprayed once every week.
[2]Means followed by the same letter in each column were not significantly different at 0.01 level by Duncan multiple range test (p = 0.01).
[3]Predators were released at the rate of 100,000/ha in previous year in the same plots.

when 16 million predators were released into 160 hectares in 4 different areas of mulberry groves, the spider mite population was checked by predators for the whole season (Table 4).

Table 4. Mass releases of 100,000 *Amblyseius womersleyi* per hectare against kanzawa spider mites in mulberry groves in spring 1984

Area	No. of samples	Prerelease density of mites (mites/10 leaves)[1]		Post release density of mites (mites/10 leaves)[1]			
				Predator non-released plots		Predator released plots	
		Spider mites	Predators	Spider mites	Predators	Spider mites	Predators
Hualien	200	4.14±1.18A	2.29±0.79*b*	–	–	1.48± 0.06B	3.55±0.09*a*
Pingtung	200	4.11±3.54B	0.35±0.57*a*	6.43± 0.35A	0 *b*	1.49± 0.21C	0.43±0.05*a*
Nantou	200	126.68B	5.77*a*	167.59±30.91A	3.08±6.16*b*	33.83±22.85C	5.51±0.81*a*
Taitung	200	0.13A	0.38*c*	0.50± 0.58A	3.13±2.16*b*	0.19±0.512A	4.78±2.22*a*
Over all		33.74 B	2.11 *c*	58.18 A	2.26 *b*	9.25 C	3.57 *a*

[1]Means followed by different letters in capitalized or italic showed significant difference by student t-test between pre- and post-releases of predator, respectively.

Net Income of Mass Releases of *A. womersleyi*: Predator release resulted in a better quality and a higher yield of silkworm cocoons. The mulberry leaves produced per hectare each spring are sufficient to raise 20 boxes of silkworms at 25,000 eggs/box. The total gross income of spring season from predator released plots were NT$145,285/ha compared to NT$129,524/ha from non-released plots. Profit of biological control of spider mites with mass release of *A. womersleyi* was NT$14,861/ha over non-control program.

In conclusion, mass release of predators against spider mites in mulberry groves at 100,000 predators per hectare resulted in a promising control and a benefit of NT$14,861/ha. Therefore, based on the economic benefit index, biological control is three times better in controlling spider mite population than chemical control.

COMMENTS ON BIOLOGICAL CONTROL IN TAIWAN

PART I

By

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During November 6–16, 1984, Agricultural Research Institute, Experiment Stations and Universities in Taiwan were visited. In addition reports on various biological control projects were reviewed at TARI. The following are some general and specific comments.

GENERAL COMMENTS

Researchers: There is a great deal of enthusiasm and motivation to do good work among researchers. They are eager to learn and to accept new ideas. Perhaps because the program is new in many cases, the work done appears to be in the preliminary stages. Excellence can be ephemeral; don't let it fade away.

Administration: There are at least three approaches to research administration: (1) Administrators taking a strong leadership in deciding the direction of the projects, (2) researchers taking the leadership in deciding the direction of research projects, and (3) both administrators and researchers taking the leadership.

Evidently Taiwan has, though not entirely, taken the first approach. It seems to be working out exceedingly well. The administrative work is excellent; the goals are clearly spelled out. Because of this there appears to be a strong cooperative effort in attaining the goals of crop protection by use of biological control agents.

Objectives of This Report: Because of the renewed emphasis on biological control in Taiwan there is much research to be done and much of the work at present, except that on sugarcane, appears to be in preliminary stages. The main goal is to develop biological control methods that are suitable for the Taiwan cropping systems. Listed below are some suggestions.

MAPPING PEST DISTRIBUTION

Taiwan, a relatively big island, is an area of great ecological diversity. This is reflected in the diversity of crops and pests. It would be helpful for researchers and administrators if there was a map showing the incidence of the major pests in Taiwan. Biological control inputs can be intensified in areas of serious pest problems and reduced in other areas. The idea of Dr. Chiou-nan Chen of

establishing satellite mass-rearing laboratories in areas of high pest incidence is an excellent one and pest maps would be helpful in locating suitable sites.

It may be also helpful to map distribution of pests within fields. Due to cultural and ecological factors some pests tend to be abundant in one part of the field but not in others. It might save monitoring and "treatment" costs if distributional patterns were known.

TRICHOGRAMMA PROGRAM

The mass-rearing of *Trichogramma* at Hsing-ying was impressive. The program is well organized and the facilities are good. However, I would like to comment on four areas: (1) host rearing, (2) quality control, (3) field releases, and (4) economic threshold.

Host Rearing: In the existing procedure the immature stages of *Corcyra* develop in the rearing medium and the adults emerge directly into the rearing room where they are captured by net when needed.

It is suggested that attempts be made to separate fully grown larvae (or pupae) from the rearing medium. To do this it is necessary to start with eggs of uniform age and to separate fully grown larvae from the medium a day or so before pupation. They can be counted and placed in a series of oviposition cages (perhaps 1 x 1 x 1 m). Eggs to be used for *Trichogramma* parasitization can be obtained from adults that emerged in these cages. When oviposition rates of *Corcyra* begin to decline they should be destroyed and replaced by new stock.

The time to separate fully grown *Corcyra* larvae from the rearing medium must be determined. The day-degree method can be used if the member of day-degrees required for the development of eggs and larvae were known. Day-degrees can be calculated by different ways, but perhaps summation from thermograph charts of the rearing room would be the simplest. If constant temperature rooms are used, the number of days can be used to determine the time of separation of larvae from the rearing medium.

This procedure would make it possible to handle the adults easily and to identify and discard non-productive stock early.

Quality Control: The importance of the quality of *Trichogramma* reared and released can not be over estimated. To assure quality it is necessary to monitor periodically the quality of parasites produced. The method of determining quality must be worked out. Some of the indicators of quality (or lack of it) are: (1) population parameters, (2) longevity, (3) fecundity and (4) flight or dispersal capabilities. Using some of these parameters it might also be possible to select out and mass-rear superior strains of *Trichogramma.*

Field Releases: For the control of the sugarcane borer the *Trichogramma* release interval was reported to be once every two weeks. Considering the continuous egg-laying behavior of *Ostrinia*, short life span, and dispersal capacity of *Trichogramma*, this interval appears to be too long. This interval when used in corn fields would result in periods in which there would be insufficient number of parasites. Theoretically, the life span and release interval should be related; i.e., the shorter the life span the shorter the release interval.

The number of release points per unit area as well as the number of parasites to be released in corn fields should be more critically determined in areas of high and low *Ostrinia* egg densities.

The excellent report of Dr. H. C. Chiang should be helpful in determining number of release points per unit area as well as the number of parasites to be released. The benefit/cost ratios are involved here and should be taken into consideration; the higher the release efforts, the higher the cost of control.

Economic Threshold: Tentative economic threshold based on egg density of *Ostrinia* should be established. *Trichogramma* releases can be made according to the estimated threshold. Determination of precise threshold values is not necessary; for practical work estimated values are adequate. Some aspects of this work are done by Dr. Shui-chen Chiu and co-workers at TARI. It is hoped that they continue their work.

BIOLOGICAL CONTROL OF MISCELLANEOUS CROPS

Coconut Beetle (*Brontispa longissima*): This project seems to be making excellent progress in certain areas. There are evidences that coconut trees are recovering from *Brontispa* attack following the release of *Tetrastichus brontispae*, especially in areas where coconut trees are in mixed forests. Further efforts should be made to introduce *Tetrastichus* and other parasites from as many areas as possible and to release them in different ecological areas.

Other Crops: Efforts should be made to determine the key pests of different crops. Key parasites of the different pests should also be determined. If necessary foreign introductions of natural enemies should be made.

CATALOGUE

As suggested by others, efforts should be made to make a list of natural enemies and their hosts in Taiwan. Such a catalogue would be useful in importation, evaluation, and international exchange of natural enemies. Cooperative work with taxonomists would be desirable.

WORKSHOP

There appears to be a need for a more balanced research program between laboratory and field work. A short workshop on commonly used field techniques should be helpful.

PART II

By

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SOME CONSIDERATIONS IN IMPLEMENTATION OF BIOLOGICAL CONTROL PROGRAMS

Implementation: The scope of the current importation program in Taiwan has already produced very significant results. The international liaison maintained is impressive and undoubtedly will lead to further exchanges of both natural enemies and biological control information. The current achievements include: (1) The establishment of a quarantine facility which meets the current needs and provides the opportunity to train personnel in quarantine procedures. (2) The building of a full scale quarantine facility to be completed in 1985 reflects a long term view in planning and development. (3) The organization of a committee to review the requests for importing and utilizing natural enemies is crucial and its establishment again reflects excellent planning. Relative to the last item, the committee will need a satellite group of scientists to help in particular pest and/or natural enemy situations.

Another aspect may be suggested related to record keeping. The Beneficial Insect Introduction Laboratory of the USDA has started the ROBO program. It is aimed at streamlining records on the importation, movement, release, establishment, recolonization, dispersal and culture of exotic beneficial organisms in the U.S. (BIIL material enclosed). A comparable system is needed in Taiwan and should be initiated as importation is just at its beginning. If Taiwan adopted a similar system, there would be the possibility to interface the two systems in the future.

Mass Production of *Trichogramma*: I was much impressed by the planning and operation of the *Trichogramma* production Center at Wu-shu-lin, Hsing-ying. It utilizes existing expertise by transferring personnel and utilizes existing facilities by remodeling vacant buildings. This approach saved both money and time, and made it possible to start production with a very short lead time. It is a "crash program" planning at its best.

After viewing the actual operation, additional opportunities for increasing efficiency could be explored. (1) To lower the ceiling of the rearing room (or place a false ceiling) to reduce the height workers have to reach upward. (2) To add a cloth screen inside of the door to reduce moth escape. (3) To provide to the worker collecting moths a face mask which is connected by a plastic hose to air outside of the rearing room, to reduce inhaling scales. (4) Another method as suggested by Dr. Nishida is to sort out pupae and let moth emergence take place in a cage, and place fresh egg cards in the same cage and let oviposition take place.

The process of preparing egg cards is an important step. There are also opportunities for exploring modifications. (1) Test industrially manufactured sticky surfaces (such as the airline tags enclosed or similar products) to see if it is sticky enough to catch eggs. If it works and if large pieces can be purchased cheaply, much labor can be saved. (2) Test glues which can be applied and stored without losing stickiness. In both above cases, the effect on egg viability must be tested.

Mass Production in General: Successful mass production starts with knowledge on biology of the agents involved (as pointed out in my Symposium presentation). A few more aspects could be explored.

(1) Selection and breeding of the stock. This process could be a aimed at (a) faster developing and more prolific lines (as in my manuscript), (b) resistance to pesticides (as in predacious mites), (c) dispersal capability by designing the oviposition chamber so that only the parasites which can fly a distance will reach the host eggs and propagate (as I mentioned during the question and answer sessions).

(2) Finding surrogate hosts which can be easily and economically produced, and developing *in vitro* rearing methods.

(3) Quality control as pointed out by Dr. Nishida.

Storage: The needs of parasitoids in the field at a particular time depends on the weather conditions and crop and pest development. Advanced planning and projection are crucial, yet they are not infallable. Thus methods of storing an extra supply need to be fully explored, involving knowledge on physical ecological conditions under which parasite viability can be maintained for a lengthy period. Temperature, humidity and photoperiod are factors to be considered.

Field Dispensing: My Symposium manuscript provides a theoretical basis of determining the minimum number of release sites to produce desired degree of parasitism. This point will not be crucial if parasites can be broadcasted by mechanical means or if human labor is plentiful. Still, some aspects need to be explored. (1) Appropriate containers in which parasites are protected from natural elements and predation. Both shape and color are factors to be studied. (2) Determining the most appropriate period of aging of parasites before release. (3) Finding kairomones which can increase search efficiency of parasites. (4) Use a high release rate first in order to establish the effectiveness, later may use reduced rates to establish the minimum effective rate.

International Aspects: A number of natural enemies have been imported from abroad, such as Indonesia, Guam and Hawaii. With the rich fauna in Taiwan there must be many biological control agents unique to Taiwan and useful to other countries. Several aspects could be explored in enhancing the exchange of material and information in biological control on a global scale.

1. **To Initiate An Inventory of Agricultural Pests and Their Natural Enemies.** This information will be the basic data for exchanges. Prof. T. H. Su of the National Chung Hsing University discussed this idea with Dr. Nishida and me. Taiwan already has the organization and expertise for this undertaking. Taxonomic identification can be provided by scientists in universities and institutes and the field survey can be performed by personnel of the six District Agricultural Improvement Stations, search of literature on world distribution of agricultural pests and availability of biological control agents could also be initiated. The Parasite Catalogue by Thompson of the Commonwealth Institute of Biological Control could serve as the starting point of this search.

2. **Contacts with Foreign Institutions and Scientists.** A beginning can be made through personal contacts. Taiwan already is sending scientists to international congresses and conferences and foreign scientists have also been invited to visit Taiwan. This program could be expanded. Additionally, key personnel of COA may be encouraged, even supported, to become members of professional societies abroad, such as the International Organization of Biological Control, the Entomological Society of America. Through such memberships, scientists in Taiwan will receive information on

current activities in biological control on the international scene. They can also submit information on activities in Taiwan to the societies' publications such as newsletter and bulletins, to bring Taiwan achievements to international awareness.

Epilogue: In my Biological Control Symposium presentation I mentioned as possibilities and need for further research in application of biological control; (1) selection and breeding of parasite lines of particular characteristics, (2) developing *in vitro* rearing or more economical surrogate host eggs, (3) finding kairomones to increase searching efficiency, (4) improving dispensing technology and (5) improving forecasting strategic timing of dispensing. It is interesting that an article by Greany, Vinson and Lewis appeared in the December 1984 issue of Bioscience mentioned three of the five items. Under selection and breeding, that article emphasized host preference while I emphasized developmental and reproductive rates. In fact, resistance to pesticides and dispersal capacity are also possibilities. One point needs to be emphasized is that any of the above requires research in basic ecology and biochemistry of the parasitoids and their hosts. I was impressed by the fact that cooperation between scientists of different disciplines and in different institutions exists, or is potentially feasible.

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臺灣作物害蟲之生物防治

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