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Review Article

Biological control of the coconut whitefly, *Aleurodicus pulvinatus*, in Nevis

Moses T.K. Kairo[1], Vyjayanthi F. Lopez[1], Gene V. Pollard[2] and Robelto Hector[3]

[1]CABI Bioscience, Caribbean and Latin American Centre, Gordon Street, Curepe, Trinidad and Tobago

[2]Food and Agriculture Organization of the United Nations, Sub-Regional Office for the Caribbean, P.O. Box 631-C, Bridgetown, Barbados

[3]Department of Agriculture, Nevis Island Administration, St Kitts and Nevis

Abstract

Aleurodicus pulvinatus is a serious pest of coconuts and many ornamental species. Although it is native to certain parts of the Neotropics it appears to have become introduced into several islands in the Caribbean. Furthermore, it has the potential to become more widespread. A recent project has been focused on biological control of *A. pulvinatus* in Nevis and this work offers a good case study of challenges/problems in implementing this kind of project. Information on the taxonomy of the pest and its natural enemies is reviewed. Surveys for natural enemies carried out in Trinidad and Tobago showed that species within the genus *Aleurodicus* share a number of natural enemies. The natural enemy complex attacking *Aleurodicus* spp. includes several species of Aphelinidae in two genera (*Encarsiella* and *Encarsia*), one Encyrtidae (*Metaphycus* sp.) and several species of *Nephaspis* (Coccinellidae). The Code of Conduct for the Import and Release of Exotic Biological Control Agents was followed and thus the work provides a good model for other countries wishing to implement the Code. *Encarsiella* sp. D was introduced into Nevis and appears to have become established.

Introduction

Although the economic significance of coconuts (*Cocos nucifera*) as a crop in the Caribbean has diminished over the years, they are nevertheless still important particularly for the local fresh coconut water market. In addition they are important components of the landscape, contributing to the aesthetic beauty of many of the islands where tourism plays a key role in the economy. In recent years, several homopteran insects have become serious pests of coconuts on a number of islands, causing major concern (Barrow, 1991; Pollard, 1995, Martin & Watson, 1998; J. Laudat, P. Graham & S. Edwards, pers. comm.). In Nevis, for instance, the problems were so severe that the Food and Agriculture Organization of the United Nations (FAO) was requested by the Government of St Kitts and Nevis to provide assistance in the form of a Technical Cooperation Project (TCP/STK/4551): Management of Foliage Pests of Coconut in Nevis. As part of the initial activities of the project, a survey of the pests and their natural enemies was carried out in 1995. The most common pests were identified as two whitefly species, *Aleurodicus pulvinatus* (Maskell) (= *A. iridescens* Cockerell) and *Aleurotrachelus atratus* Bondar (Aleyrodidae), and the scale *Aspidiotus destructor* Signoret (Diaspididae). However, only *Aleurodicus pulvinatus* was considered to be of sufficient significance to require control measures (Cock & Watson, 1995).

The fundamental role of biosystematics in classical biological control cannot be understated. Often the identity of a pest species may be in doubt, and if this is not clarified, efforts at biocontrol may be wasted. For example, in Nevis, the whitefly causing problems was first thought to be *Aleurodicus cocois* Curtis (Barrow, 1991; Pollard, 1995). This species became sufficiently important as a pest of coconuts in Barbados to warrant a biological control programme in the 1950s. Of several natural enemies introduced from Trinidad during 1950 and 1951, the parasitic wasp, *Encarsiella noyesi* Hayat became established and provided excellent control (Cock, 1985). It was only after detailed biosystematic studies that the taxonomy of the whitefly in Nevis was clarified. Thus, its true identity was determined to be *A. pulvinatus,* which was synonymised with *A. iridescens* (Martin & Watson, 1998).

Aleurodicus pulvinatus is indigenous to Central and South America and several Caribbean islands, where a number of natural enemies normally keep its populations under control. During surveys for natural enemies in Nevis, although several species were found attacking the whitefly (see Table 3), they apparently did not provide adequate control (Cock & Watson, 1995). Natural enemies that had co-evolved with *A. pulvinatus* would be expected to have specialized in preying upon this species and thus provide good levels of control. The lack of such specialist natural enemies suggested that *A. pulvinatus* might be exotic to Nevis. Hence, classical biological control was suggested as a sustainable long-term solution. Based on the excellent results following introduction of natural enemies in Barbados for control of *A. cocois,* prospects for success appeared good (Cock, 1985).

The Pest

Origin and distribution

Based on Mound & Halsey (1978) and material in the Natural History Museum, London, UK (NHM) and the US National Museum of Natural History, Beltsville, Maryland (NMNH), *A. pulvinatus* occurs in Central and South America and the Caribbean. Current distribution records of *A. pulvinatus* include: Antigua, Barbados, Grenada, Jamaica, Montserrat, St Kitts and Nevis, St Vincent and the Grenadines, and Trinidad and Tobago in the Caribbean, Mexico, Panama, Belize, Bolivia, El Salvador, Honduras and Nicaragua in Central America, and Brazil, Colombia, Ecuador, Guyana, Peru and Venezuela in South America (Martin & Watson, 1998). It appears likely that the whitefly has been expanding its geographical range within the Caribbean. Thus, it may be a new introduction in some of the islands, notably Antigua, St Vincent and the Grenadines, and Grenada where it is apparently causing severe damage (J. Laudat, P. Graham & S. Edwards, pers. comm.). The most likely mode of transfer is through movement of nursery plants, particularly ornamentals.

The purpose of this paper is to summarize pertinent information on biological control for other countries faced with an invasion by the whitefly.

Biology, damage and host plants

The adult female lays its eggs in a typical spiral pattern just under the lower leaf surface. Studies on developmental biology in Trinidad at 26 ± 2°C and 60 ± 5% relative humidity revealed that the total life cycle takes 30-35 days, with the egg stage lasting 10-12 days, the first three instars 3-5 days each and the fourth instar/pupa 5-8 days.

As with other Aleyrodidae, damage is caused by the immature stages, which feed by sucking plant sap. *Aleurodicus pulvinatus* has a fairly wide host range encompassing 17 families (Table 1). Feeding by the larvae reduces plant vigour and predisposes plants to attack by other insects. The larvae also produce a sugary excretum called honeydew, which encourages growth of black sooty moulds on leaf surfaces. This is unsightly and also reduces the ability of the plant to photosynthesize. The appearance of the plants is further marred by the appearance of the insects: both eggs and larvae are covered by an unsightly white waxy material. No studies have been carried out to quantify economic losses due to the pest but this can potentially be high. Apart from loss of plants and cost of replacement, there is the high cost of control measures in terms of both materials and equipment and potential adverse effect on the environment. The impact on tourism may include loss of repeat business.

Surveys for Natural Enemies in Trinidad and Tobago

In view of the fact that *A. pulvinatus* is not a serious pest in Trinidad and Tobago, it was assumed that effective natural enemies were present. Thus surveys were carried out in various parts of Trinidad and Tobago between 1996 and 1998, and focused on determining the natural enemy complex found on *Aleurodicus* spp. in general. The information obtained was also useful in deducing the host range of selected natural enemy species. A list of parasitoids found attacking *A. pulvinatus* and other closely allied species is given in Table 2.

Eight species of parasitoids were recorded: five Aphelinidae (two *Encarsiella* and three *Encarsia*), two Encyrtidae (both *Metaphycus*) and one Signiphoridae (*Signiphora* sp., possibly a hyperparasitoid). Among the predators, coccinellids in the genus *Nephaspis* were most important. A summary of the natural enemies specifically found attacking *A. pulvinatus* in the Caribbean Basin is given in Table 3.

The surveys revealed that species in the genus *Aleurodicus* appeared to share a number of natural enemy species. Thus for Caribbean countries where *A. pulvinatus* becomes a serious pest, it will be prudent to carry out surveys to determine which natural enemies are already present before considering introduction of new ones. This is because natural enemies of other *Aleurodicus* species may adapt to exploit *A. pulvinatus*, in which case a new introduction may not be necessary.

Amongst the parasitoids in Trinidad and Tobago, two *Encarsiella* species (*Encarsiella* sp. D and *E. noyesi*), were the most important. With few exceptions, *Aleurodicus* spp. encountered on various hosts throughout the country were always attacked by one or both of these species (Table 2). Percent parasitism levels of up to 95% were observed. Often more than one parasitoid species occurred, and in such cases *Encarsiella* sp. D invariably dominated. In isolated sites where only one species was present, high levels of parasitism were also recorded. Of the predators present, *Nephaspis* spp. were clearly the most important (Lopez *et al*., 1997). However, an unidentified species of *Nephaspis* was recorded during surveys in Nevis and hence the introduction of *Nephaspis* from Trinidad was not considered. On the basis of these field observations, and in the light of the previous successful control of *A. cocois* in Barbados, *Encarsiella* sp. D and *E. noyesi* were prioritized for detailed studies.

The Biocontrol Agents: *Encarsiella* Species

Taxonomy

The genus *Encarsiella* belongs to the order Hymenoptera, superfamily Chalcidoidea, Family Aphelinidae. At one time, the genus was synonymised with *Dirphys* but was later reinstated as *Encarsiella* with six described species and two new species (Polaszek & Hayat, 1992). Five species have since been added to this list (Chou & Chou, 1994; Huang & Polaszek, 1996) and several more are currently in the process of being revised/described (A. Polaszek, pers. comm.).

Biology

Many genera of Aphelinidae have complex developmental biologies involving autoparasitism (Viggiani, 1984). Mated females lay fertilized, diploid eggs in young and adult stages of Homoptera (whiteflies, mealybugs and scale insects) and these develop into female larvae which feed as primary endoparasitoids. Haploid eggs laid by both mated and unmated females develop into males. In some species, males develop as primary parasitoids but in many others, they develop as hyperparasites on females of their own or related species. In a few species, males may develop as primary parasites of eggs of other insects such as Lepidoptera (Polaszek, 1991). The biology of *Encarsiella* spp. is poorly known. Studies on *E. noyesi* attacking *Aleurodicus dugesii* Cockerell in California have revealed the existence of entirely thelytokous populations (T. Bellows, pers. comm.). Observations in Trinidad indicate that males of both *Encarsiella* sp. D and *E. noyesi* exhibit an autoparasitic mode of life.

Table 1 Host range of *Aleurodicus pulvinatus*, based on Watson (1996), Martin & Watson 1998, and studies conducted as part of the FAO Technical Cooperation Project (TCP/STK/4551): Management of Foliage Pests of Coconut in Nevis.

Family	Genus/species	Country records[1]
Alismataceae	*Echinodorus*	not known
Araceae	*Montrichardia arborescens* ssp. *aculeata*	Guyana
Chrysobalanaceae	*Chrysobalanus icaco*	Mexico
	Licania	not known
Combretaceae	*Terminalia catappa*	Trinidad & Tobago
Euphorbiaceae	*Hura crepitans; Jatropha*	Costa Rica
Guttiferae	*Vismia*	Trinidad & Tobago
Lacistemataceae	*Lacistema*	Panama
Lauraceae	*Persea americana*	Trinidad & Tobago
	undetermined host	Belize
Moraceae	*Ficus*	not known
Musaceae	*Musa*	not known
Myrtaceae	*Psidium guajava*	Belize; St Kitts & Nevis; Trinidad & Tobago
Palmae	*Cocos nucifera*	St Kitts & Nevis; Trinidad & Tobago
Piperaceae	*Piper nigrum*	Brazil
Polygonaceae	*Coccoloba belizensis*	Belize
	Coccoloba uvifera	Trinidad & Tobago
Rubiaceae	*Coffea canephora*	Ecuador
	Isertia hypoleuca	Panama
	Guettarda combesii	Belize
Sterculiaceae	*Theobroma*	not known
Verbenaceae	*Petrea*	not known

[1]Based on NHM (Natural History Museum, London, UK) collections and FAO Nevis project results.

Under laboratory conditions (26 ± 2°C and 65 ± 5% RH), the development of females of both *Encarsiella* species took 11-13 days from egg to prepupal stage, at which time the meconium (consisting of flat reddish-brown pellets) was discarded and the parasitoid larva was visible from the ventral surface of the whitefly pupa, which was more transparent than the dorsal surface. In 1-2 days, the empty pupal case of the whitefly hardened to form the 'mummy'. The pupa was formed inside the mummy. The mummy of *E. noyesi* was slightly smaller and not as black as that of *Encarsiella* sp. D. The pupal stage lasted 4-5 days. The total life cycle of females was thus completed in 17-20 days. Males apparently had a shorter developmental period. Since male development could in theory begin in the first instar female larva (approx. 3 days old), male development is estimated to take at least 14 days.

It was not clear if male eggs were laid together with female eggs or later when developing female larvae were already present. Both modes of egg laying have been reported amongst the Aphelinidae. It is also possible that males may develop as primary parasitoids. In *Encarsia pergandiella* Howard, males are reported to develop both as primary parasitoids and as hyperparasitoids (Hunter *et al*., 1993). To test whether this occurred in the *Encarsiella* species being investigated in Trinidad, large numbers of newly emerged, unfertilized females were released on *A. cocois.* No males, however, were recovered up to 5 weeks later.

The sex ratio under field conditions was always biased towards females, with males often accounting for only 0-5% (occasionally higher) of the numbers encountered. The size of the parasitoids also varied depending on the host insect from which they were reared. For example, *Encarsiella* sp. D. reared from *Aleurodicus maritimus* Hempel measured 0.64 mm, from *A. pulvinatus* 0.80 mm and from *A. cocois* 1.0 mm, on average.

Host range

All known records of *Encarsiella* species from the Neotropics are from Aleyrodidae (Table 4). While two species have been recorded from *Aleurothrixus floccosus* Maskell, all other records are from *Aleurodicus* spp. (A. Polaszek, pers. comm.). Based on field studies in Trinidad, *E. noyesi* attacks three species of *Aleurodicus* (Table 3). Other whitefly species were not found to be attacked even when parasitism levels on associated *Aleurodicus* spp. were high. For example, *Aleurothrixus floccosus* associated with parasitized *Aleurodicus maritimus* on guava, and *Paraleyrodes* sp. occurring with parasitized *A. cocois* on coconut were not attacked by *E. noyesi* or *Encarsiella* sp. D. *Aleurodicus* spp. therefore appear to be the preferred hosts for both *Encarsiella* sp. D and *E. noyesi.*

The host range of the males in both species is less well known. There is some evidence that males of one species could develop hyperparasitically on female larvae/pupae of the other species and vice versa. During field studies, males were never recovered from *Encarsia* spp. which occur in the same habitat. However, this was not sufficient evidence to discount the possibility that these species could be attacked. Indeed, although obligate autoparasitoids are known, most species are facultative and males may develop in several host species.

Table 2. Parasitoids reared from *Aleurodicus pulvinatus* and related Aleyrodidae in Trinidad & Tobago, 1996-98.

Species	Ex: host	Host plant
Encarsiella noyesi Hayat	*Aleurodicus pulvinatus* (Maskell)	*Coccoloba uvifera* (seagrape) *Terminalia catappa* (tropical almond)
	Aleurodicus cocois Curtis	*Cocos nucifera* (coconut)
	Aleurodicus maritimus Hempel	*Psdium guajava* (guava) *Cajanus cajan* (pigeonpea)
Encarsiella sp. D	*Aleurodicus pulvinatus*	*Coccoloba uvifera* *Psdium guajava* *Cocos nucifera*
	Aleurodicus cocois	*Psdium guajava*
	Aleurodicus maritimus	*Cajanus cajan*
Encarsia guadeloupae Viggiani	*Aleurodicus pulvinatus*	*Coccoloba uvifera*
	Aleurodicus cocois	*Cocos nucifera* *Veitchia merrillii* (manila palm)
	Aleurodicus maritimus	*Psdium guajava*
	Lecanoideus mirabilis (Cockerell)	*Polyalthia longifolia* (ashoka tree)
Encarsia sp. nr. *meritoria* Gahan sp. A. (= *E. ?haitiensis*)	*Aleurodicus pulvinatus*	*Psdium guajava*
	Aleurodicus cocois	*Cocos nucifera* *Veitchia merrillii*
	Aleurodicus maritimus	*Psdium guajava* *Cajanus cajan*
	unknown ?*Aleurodicus* sp. or ?*Lecanoideus* sp.	*Pimenta racemosa* (bay leaf tree)
	Aleurothrixus floccosus Maskell	*Spondias dulcis* *Citrus* sp.
Encarsia sp. nr. *meritoria* Gahan sp. B	*Aleurodicus cocois* + ?*Aleurotrachelus* sp.	*Cocos nucifera*
	Aleurodicus maritimus	*Psdium guajava*
Metaphycus sp. 1	*Paraleyrodes* sp.	*Cocos nucifera*
Metaphycus sp. 2	*Aleurodicus cocois*	*Cocos nucifera*
	Aleurodicus maritimus + *Aleurothrixus floccosus*	*Psdium guajava*
Signiphora spp. (hyperparasitoids)	unidentified parasitoid of *Aleurodicus cocois*	*Cocos nucifera*
	unidentified parasitoid of ?*Aleurotrachelus* sp.	*Cocos nucifera*
	unidentified parasitoid of ?*Aleurotrachelus* sp.	*Capsicum* sp.

Table 3. Known natural enemies of *Aleurodicus pulvinatus* in the Caribbean Basin area.

Country	Natural enemy	Family	Species	Reference
Belize	Parasitoids	Aphelinidae	*Encarsia* sp. near *meritoria* (= *E.* ?*haitiensis* in literature) *Encarsiella noyesi* Hayat	Watson 1996
		Eulophidae	*Entedononecremnus* sp.	
Nevis	Parasitoids	Aphelinidae	*Encarsia ?guadeloupae* *Encarsia guadeloupae* Viggiani	Watson 1996
		Eulophidae	*Aleuroctonus vittatus* (Dozier)	
	Predators	Coccinellidae	*Delphastus nebulosus* Chapin *Nephaspis* sp.	
		Chrysopidae	*Neosuarius collaris* Schneider	
Trinidad & Tobago	Parasitoids	Aphelinidae	*Encarsiella noyesi* *Encarsiella* sp. D *Encarsia ?haitiensis* *Encarsia guadeloupae*	Nevis project[1]
	Predators	Coccinellidae	*Nephaspis* spp. *Scymnus* spp.	
		Chrysopidae	unidentified species	
		Syrphidae	unidentified species	
		Phytoseiidae	several species of predatory mites	
		Araneae	several species of spiders	
Venezuela	Parasitoids	Aphelinidae	*Dirphys larensis* Chavez	Chavez 1996

[1]FAO Technical Cooperation Project (TCP/STK/4551): Management of Foliage Pests of Coconut in Nevis.

Table 4. Host range of *Encarsiella* species.

Encarsiella spp.	Host species	Source
E. aleurodici (Girault)	unknown host	A. Polaszek, pers. comm.
E. magniclava (Girault)	*Eudialeurodicus bodkini* Quaintance & Baker	A. Polaszek, pers. comm.
E. noyesi Hayat	*Aleurodicus pulvinatus* (Maskell)	Nevis project[1]
	Aleurodicus cocois Curtis	A. Polaszek, pers. comm.; Nevis project
	Aleurodicus maritimus Hempel	Nevis project
Encarsiella sp. A	*Aleurodicus dugesii* Cockerell	A. Polaszek, pers. comm.
Encarsiella sp. B	(no host)	A. Polaszek, pers. comm.
Encarsiella sp. C	*Aleurothrixus floccosus* Maskell	A. Polaszek, pers. comm.
Encarsiella sp. D	*Aleurodicus iridescens* Cockerell (= *A. pulvinatus*)	A. Polaszek, pers. comm.
	?*Aleurothrixus floccosus*	A. Polaszek, pers. comm.
	Aleurodicus pulvinatus	Nevis project
	Aleurodicus cocois	Nevis project
	Aleurodicus maritimus	Nevis project

[1]FAO Technical Cooperation Project (TCP/STK/4551): Management of Foliage Pests of Coconut in Nevis.

Dossiers

With the ratification of the international Code of Conduct for the Import and Release of Exotic Biological Control Agents (FAO, 1996) as an International Standard for Phytosanitary Measures, it was expected that provisions of this Code would apply in the implementation of any new biological control project. This project has offered practical opportunities for training national staff in implementation of the Code and also to increase overall awareness among stakeholders. Thus the project in Nevis was carried out in full compliance with the Code. To this end, dossiers were prepared for *Encarsiella* sp. D and *E. noyesi* (Lopez *et al.*, 1998a, b). In each dossier relevant information on the pest and parasitoid species was summarized. This included an assessment of potential risks posed to non-target organisms (particularly other whitefly species and beneficial insects), to human and animal health, and to persons handling the parasitoids. Both species have a narrow host range, which appears to be restricted to *Aleurodicus* spp. The information contained in the dossiers would be relevant to any country which may wish to introduce the same natural enemies, although it may necessary to consider risks separately for each country.

The dossier on *Encarsiella* sp. D was submitted to the Department of Agriculture, Nevis in February 1998. Approval for the introduction was granted in March and the species was introduced into Nevis in April. The dossier on *E. noyesi* recommended that introduction of this species be withheld pending reports of the establishment of *Encarsiella* sp. D in order to facilitate ease of both establishment (of the parasitoid) and monitoring (of the parasitoid's establishment and its effects on the target pest).

Importation of *Encarsiella* sp. D into Nevis

In seven shipments, a total of 2739 parasitoids were sent to Nevis between April and June 1998. Introduced parasitoids were released directly in the field on coconut and another host plant, seagrape (*Coccoloba uvifera*). Two release strategies were adopted: part of the material was released into sleeve cages while the rest was released in the open. The latter proved more successful.

During field releases, a eulophid parasitoid, *Aleuroctonus vittatus* (Dozier), recorded in low numbers during surveys in 1995 (Cock & Watson, 1995), was found to be relatively abundant. The role of this parasitoid needs to be looked at in the overall assessment programme.

It was not possible to conduct regular sampling to assess the impact of the natural enemies; however, there is ample evidence that the parasitoid has become established and is spreading from initial release sites.

Conclusions

Aleurodicus pulvinatus appears to be continuing to expand its distribution within the Caribbean. However, a useful framework for carrying out biological control has been established and has been described here. This should be useful for any countries wishing to implement control programmes against the pest.

Although extensive monitoring of the situation in Nevis was not sustained, there was evidence to suggest that *Encarsiella* sp. D became established. However, there is still need for a more comprehensive evaluation of the effectiveness of the introduced natural enemy.

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