Can Oecophylla smaragdina be used to suppress incidence of CVPD in citrus orchards in Indonesia?

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Abstract. Citrus vein phloem degeneration (CVPD) is the Indonesian name for the Asian form of the devastating and incurable citrus disease known internationally as huánglóngbìng. It is associated with a phloem-limited pathogen, 'Candidatus Liberibacter asiaticus' (CLas) and transmitted by the Asiatic citrus psyllid (ACP), Diaphorina citri. ACP originated in South Asia but was first observed on citrus in 1900 in Java to where it may have been introduced decades earlier on lemon or lime seedlings brought from South Asia to reduce the incidence of scurvy among European sailors and in colonial settlements. CLas appears to have been introduced to the Pasar Minggu area of Jakarta in the 1940s from southern China, after it was introduced to Guǎngzhōu, directly or indirectly, from South Asia in the late 1920s–early 1930s. Minimising incidence of the disease relies on planting pathogen-free trees, removal of infected trees, and unstainable use of synthetic pesticides that do not prevent spread of the disease. Parasitoids and predators of ACP are killed by the pesticides. Evidence from China and Việtnam suggests that effective management of the disease may be feasible if the weaver ant (semut rangrang), Oecophylla smaragdina, is deployed, cultivated, and managed in orchards.
Keywords: weaver ant, biological control, Asiatic citrus psyllid, huánglóngbìng

1. Introduction

Citrus vein phloem degeneration (CVPD) is the Indonesian common name for the severe South Asian form of huánglóngbìng (HLB). It is a devastating disease of citrus and is incurable. The disease is coused by a phloem-limited pathogen, 'Candidatus Liberibacter asiaticus' (CLas: α-Proteobaceria), a pathogen most commonly transmitted by the Asiatic citrus psyllid (ACP), Diaphorina citri Kuwayama [Hemiptera: Sternorrhyncha: Psyllidae]. Eastward spread of the disease from northwest South Asia has progressively inflicted serious economic havoc on citrus cultivation throughout Asia since the 1800s. The psyllid and the pathogen are now widespread in Asian countries and the American countries [1] and most recently have been recorded in several countries in Africa.[2-5]

Symptoms of the disease, ascribed to damage caused by D. citri, were first recorded in the Punjab in the 1920s.[6] In extreme cases, trees suffered complete defoliation. Husain and Nath [6] concluded that, apart from defoliation and loss of sap, the nymphs also injected some toxic substance into plant tissues during feeding. Undersized fruit, and poor and insipid juice were attributed to this 'toxin', and branches not directly attacked became prematurely dry. Descriptions of citrus maladies observed in India [7-9] and China [10] before 1920 have been incorrectly interpreted by many contemporary authors, including Capoor [9], Zhao [11], da Graça [12], and Bové ([1, 13], as symptoms of HLB. Oft repeated in the literature (including Zhao [11], da Graça [12], Bové [1, 13] is that CLas originated in China; however, there is no evidence for this. Also, no evidence was found that it evolved with Citrus, but it may have evolved in association with a Citrus relative. Records suggest that it could have been introduced to mainland China with plants imported from Indochina between 1929 and 1934 shortly

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before D. citri was first recorded on the mainland, in Guǎngzhōu, in 1934.[14-16] We are currently considering a possible origin of the pathogen in the Horn of Africa, transmission there by the African citrus psyllid (Trioza erytreae (Del Guercio) [Triozidae]) and/or dodder (Cuscuta spp. [Solanales: Convolvulaceae]) from citrus relatives and/or introduced citrus cultivars and spread from there in infected plants taken to northwest India during historical migration and trade between Africa and India, and possibly by Portuguese colonial activities in Africa and India. We regard this as a more likely scenario than the timing of events related to speciation of liberibacters associated with the initial evolution of Rutaceae in Gondwana and subsequently on the Indian plate as it rifted northwards from Gondwana to collide with Asia (see [17-19].

2. Huánglóngbìng in Indonesia

Tirtawidjaja et al. [20] were the first to note the presence of HLB (as citrus vein-phloem degeneration 'virus') in Indonesia. They commented that it had been spreading in Indonesia from 1950. Its importance was felt as early as 1948 in the Pasar Minggu area on Siem mandarin (Citrus reticulata Blanco 'Siem': syn. C. suhuiensis Hort. ex Tan.) (Cortez [21] Aubert et al. [22]). In 1964, the disease was widespread in Java, and surveys before 1980 showed that it was also present in Sumatra, but not in Borneo, Sulawesi, Madura and Lombok, and of limited occurrence in backyards in Makassar.[23] The widespread occurrence of HLB in Java and Sumatra was attributed by Tirtawidjaja [23] to movement of a certain mandarin variety from nurseries in Pasar Minggu in Jakarta. Aubert [24] commented that it was through Javanese planting material that HLB and D. citri were disseminated over the entire archipelago. However, he noted that its presence in Ende and Timor, where it had only recently been introduced, was limited to scattered small foci and easy to eradicate. Weinert et al. [25] detected HLB in Timor-Leste (East Timor) and in nearby Papua New Guinea, in Australasia.[26].

The spread of D. citri from its native South Asia to East and Southeast Asia appears to have been linked to movement of psyllid-infested lemon and lime seedlings from South Asia by European colonial powers as they sought to address the incidence of scurvy (vitamin C deficiency) in sailors and colonial settlements. The psyllid was first recorded in the Lands Plantentuin te Buitenzorg, now Kebun Raya Bogor (Bogor Botanical Garden), in 1900. It was recorded in Timor in 1905 and Ambon in 1907 and was described in 1907 from a region of northern Taiwan that was once part of a Dutch colony.[27]

D. citri populations suppression and low incidence of HLB in citrus orchards in Asia relies almost solely on multiple applications, sometimes weekly or more frequently, of synthetic pesticides that do not prevent inevitable, often rapid, spread of the disease.[27] The effectiveness of natural enemies, including the primary parasitoids, Tamarixia radiata (Waterston) [Hymenoptera: Eulophidae] and Diaphorencyrtus aligarhensis (Shafee, Alam & Agarwal) [Hymenoptera: Encyrtidae], entomopathogens, and numerous predatory species, is severely hampered by use of the pesticides.[27, 28] It is axiomatic that spread of HLB cannot be prevented by natural enemies, but limits on rates of spread of the disease can be as effective as applications of synthetic pesticides in well-managed orchards.[27] The effectiveness of natural enemies can be enhanced through incorporation mineral oils, applied in spays as dilute aqueous emulsions, into integrated pest management programs. Mineral oils alone can be as effective as synthetic pesticides.[29-32]

3. The golden weaver ant

Oecophylla smaragdina Fabricius [Hymenoptera: Formicidae] is a tree-dwelling ant that has been widely overlooked for the biological control of D. citri in Asia. It is native to subtropical and tropical regions of Asia and Australasia and occurs naturally throughout Indonesia.[33] It is one of two extant species of Oecophylla, the other being O. longinoda Latreille in tropical Africa.[34, 35] Commonly known as the weaver ant, golden weaver ant, green tree ant and yellow tree ant in English, huángjīngyǐ in Mandarin, and semut rangrang in Indonesian.

Weaver ants from northern Australia are used to make boutique gin and cheese (Good Weekend, The Sydney Morning Herald, 29 May 2021; [27]). In Java, the larvae and pupae called 'kroto' are harvested in the wild from trees and sold as songbird feed and fishing bait . (Césard & Azhar [36]). This brings substantial income to numerous rural households.[37] In addition to 'kroto', the ant is used in Asia for Indian and Chinese traditional medicines, and as a prized human delicacy. Increased interest in ant consumption has caused high demand in all regions of Thailand.[38] Harvesting ants in nature is profitable, and will put pressure on local populations of O. smaragdina has the potential to lead to unsustainable overexploitation of natural habitats [38]. Sribandit et al. [38] also discuss ant farming as a potential solution to detrimental impacts of exploitation of natural populations of the ant. Offenberg and Wiwatwitaya [39] concluded that harvesting of the ant in mango orchards was compatible with biological control and that ant yields could be increased with appropriate management.

Oecophylla smaragdina was the first insect used by humans to control large insect pests (caterpillars and stinkbugs) on citrus some 1700 years ago near Hà Nội, which was then part of the Chinese Han Dynasty province of Jiāozhǐ ('Chiāo-chǐh').[40] For centuries it has been reared to suppress populations of citrus pests in orchards in China and Indochina.[40, 41] Records of phytophagous pests in Asia and Australasia whose populations, and thus the damage they cause, can be significantly reduced by O. smaragdina are summarised in Table 1.

Table 1. Phytophagous pests killed, dislodged, deterred, or repelled by *Oecophylla smaragdina* in Asia and Australasia, thereby reducing economic losses in agriculture, horticulture, and forestry.

Country	Crop	Species Taxonomic group Reference
Australia	African mahogany	fruit spotting bug, *Amblypelta lutescens* (Distant) [Hemiptera: Pentatomomorpha: Coreidae] **[84]**
		cedar shoot borer, *Hypsipyla robusta* (Moore) [Lepidoptera: Pyralidae] **[85]**
		yellow looper, *Gymnoscelis* sp. [Lepidoptera: Geometridae] **[86]**
		bush cricket, *Myara yabmanna* Otte, D & RD Alexander [Orthoptera: Gryllidae] **[86]**
	cashew	tea mosquito bug, *Helopeltis pernicialis* Stonedahl, Malipatil & Houston, [Hemiptera: Cimicomorpha: Miridae] **[87]**
		fruit spotting bug, *Amblypelta lutescens lutesens* (Distant) [Hemiptera: Pentatomomorpha: Coreidae] **[87]**
		leafroller, *Anigraea ochrobasis* Hampson [Lepidoptera: Euteliinae] **[87]**
		mango shoot caterpillar, *Penicillaria jocosatrix* (Guenée) [Lepidoptera: Noctuidae] **[87]**
	mango	mango seed weevil, *Sternochetus mangiferae* (Fabricius) [Coleoptera: Curculionidae] **[81]**
		Jarvis's fruit fly, *Bactrocera jarvisi* Tyron [Diptera: Tephritidae] **[80]**
		fruit spotting bug, *Amblypelta lutescens lutesens* (Distant) [Hemiptera: Pentatomomorpha: Coreidae] **[83]**
		mango leafhopper, *Idioscopus nitidulus* (Walker) [Hemiptera: Auchenorryncha: Cicadellidae] **[79]**
		dimpling bug, *Campylomma austrina* Malipatil [Hemiptera: Cimicomorpha: Miridae] **[82]**
		red-banded thrips, *Selenothrips rubrocinctus* [Thysanoptera: Thripidae] **[71]**
China	citrus	citrus flatheaded borer, *Agrilus auriventris* Saunders [Coleoptera: Buprestidae] **[88]**
		citrus tree borer, *Chelidonium argentatum* (Dalman) [Coleoptera: Cerambycidae] **[88]**
		black and white citrus longhorn beetle, *Anoplophora chinensis* (Forster) [Coleoptera: Cerambycidae] **[88]**
		citrus leaf-mining beetle, *Podagricomela nigricollis* Chen [Coleoptera: Chrysomelidae] **[88]**
		gold-dust weevil, *Hypomeces squamosus* (Fabricius) [Coleoptera: Curculionidae] **[41, 52]**
		grey citrus weevil, *Sympiezomias citri* Chao [Coleoptera: Curculionidae] **[88]**
		large green chafer beetle, *Anomala cupripes* Hope [Coleoptera: Scarabaeidae] **[52]**
		scarab, *Miridiba sinensis* (Hope) (syn. *Holotrichia sinensis* Hope) [Coleoptera: Scarabaeidae] **[88]**
		citrus blossom midge, *Contarinia citri* Barnes [Diptera: Cecidomyiidae] **[89]**
		Asiatic citrus psyllid, *Diaphorina citri* Kuwayama [Hemiptera: *Sternorrhyncha:* Psyllidae] **[28]**
		spined stink bug, *Rhynchocoris poseidon* Kirkaldy syn. *R. humeralis* (Thunberg) [Hemiptera: Pentatomomorpha: Pentatomidae] **[28, 52, 88]**
		green stink bug, *Nezara viridula* (L.) [Hemiptera: Pentatomomorpha: Pentatomidae] **[88]**
		chequered swallowtail butterfly, *Papilio demoleus* L. [Lepidoptera: Papilionidae] **[41]**
		swallowtail butterfly, *Papilio xuthus* L. [Lepidoptera: Papilionidae] **[88]**
		yellow flower thrips, *Thrips flavidulus* (Bagnall) [Thysanoptera: Thripidae] **[89]**
		banana flower thrips, *Thrips hawaiiensis* (Morgan) [Thysanoptera: Thripidae] **[89]**
		melon thrips, *Thrips palmi* Karny [Thysanoptera: Thripidae] **[89]**
		white flower thrips, *Thrips vulgatissimus* Haliday [Thysanoptera: Thripidae] **[89]**
	litchi	litchi stink bug, *Tessaratoma papillosa* (Drury) [Hemiptera: Pentatomomorpha: Tessaratomidae] **[41, 46]**
India	cashew	tea mosquito bug, *Helopeltis* sp. [Hemiptera: Cimicomorpha: Miridae] **[90]**
	mango	brentid beetle, *Estenorhinus* sp. [Coleoptera: Brentidae] **[91]**
		leaf twisting weevil, *Apoderus tranquebaricus* Olivier [Coleoptera: Curculionidae] **[91]**
		red cotton stainer, *Dysdercus cingulatus* (Fabricius) [Heteroptera: Pyrrhocoridae] **[91]**

		mango flower webber, *Eublemma versicolor* Walker, [Lepidoptera: Noctuidae] **[91]**
		mango shoot webber, *Orthaga exvinacea* Hampson [Lepidoptera: Pyralidae] **[91]**
		mango leaf webber larvae, *Orthaga euadrusalis* Walker [Lepidoptera: Pyralidae] **[91]**
	pongamia	stink bug, *Cyclopelta siccifolia* (Westwood) [Hemiptera: Pentatomoidea: Dinidoridae] **[92]**)
Indonesia	cashew	mosquito bug, *Helopeltis* sp. [Hemiptera: Cimicomorpha: Miridae] **[93]**
	cocoa	cocoa pod borer, *Conopomorpha* (*Acrocerops*) *cramerella* Snellen [Lepidoptera: Gracillariidae] **[94]**
	mango	mango fruit weevil, *Cryptorhynchus frigidus* (Fabricius) syn. *Cryptorhynchus gravis* Fabricius [Coleoptera: Curculionidae] **[95, 96 [a]]**
	rubber	*Amblypelta lutescens papuensis* Brown [Hemiptera: Pentatomomorpha: Coreidae] **[97]**
	teak	termites [Isoptera] **[98]**
Malaysia	cacoa	tea mosquito bug, *Helopeltis theivora* Waterhouse (syn. *H. theobromae* Miller) [Hemiptera: Cimicomorpha: Miridae] **[99]**
	mahogany	mahogany shoot borer (cedar tip moth), *Hypsipyla robusta* (Moore) [Lepidoptera: Pyralidae] **[100, 101]**)
	oil palm	bagworm, *Pteroma pendula* (de Joannis) [Lepidoptera: Psychidae] **[102]**
Papua New Guinea	coconut	palm leaf beetle (*Promecotheca papuana* Ciski syn. *antiqua* Weise and *P. opacicollis*. Gestro) [Coleoptera: Chrysomelidae] **[95, 103]**
		coconut spathe bug (*Axiagastus cambelli* Distant) [Hemiptera: Pentatomomorpha: Pentatomidae] **[104, 105]**
	hoop pine	*Araucaria* looper or millionair moth (*Milionia isodoxa* Prout) [Lebidoptera: Geometridae] **[106]**
Philippines	citrus	citrus green bug (*Rhynchocoris poseidon* Kirkaldy syn. *Rhynchocoris serratus* Donovan) [Hemiptera: Pentatomomorpha: Pentatomidae] **[107]**
		citrus rind borer (*Prays endolemma* Diakonoff) [Lepidoptera: Yponomeutida] **[108]**
Solomon Islands	cocoa	cocoa weevil (*Pantorhytes biplagiatus* (Guérin) [Coleoptera: Curculionidae] **[109, 110]**
	coconut	coconut bug (*Amblypelta cocophaga* China) [Hemiptera: Pentatomomorpha: Coreidae] **[111]**
		coconut hispine beetle (*Brontispa longissima* (Gestro)) [Coleoptera: Chrysomelidae] **[112]**
Sri Lanka	cashew	tea bug (*Helopeltis antonii* Signoret) {Hemiptera: Cimicomorpha: Miridae] **[113]**
	coconut	coconut black headed caterpillar (*Opisina arenosella* Walker) [Lepidoptera: Xyloryctidae] **[114]**
Thailand	citrus	gold-dust weevil (*Hypomeces squamosus* (Fabricius)) [Coleoptera: Curculionidae] **[49]**
	mango	mango leafhopper (*Idioscopus clypealis* (Lethierry)) [Hemiptera: Auchenorryncha: Cicadellidae] **[49]**
Việtnam	citrus	Oriental fruit fly (*Bactrocera dorsalis* (Hendel) [Diptera: Tephritidae] ***[57, 58]***
		Asiatic citrus psyllid (*Diaphorina citri* Kuwayama) [Hemiptera: *Sternorrhyncha:* Psyllidae] **[48, 60]**
		black citrus aphid (*Aphis* (*Toxoptera*) *citricidus* (Kirkaldy)) [Hemiptera: *Sternorrhyncha:* Aphididae] **[48, 60]**
		brown citrus aphid (*Aphis* (*Toxoptera*) *aurantii* Boyer de Fonscolombe) [Hemiptera: *Sternorrhyncha:* Aphididae] **[48, 60]**
		spined stink bug (*Rhynchocoris poseidon* Kirkaldy syn. *R. humeralis* (Thunberg)) [Hemiptera: Pentatomomorpha: Pentatomidae] **[60]**
		citrus butterflies (*Papilio* spp.) [Lepidoptera: Papilionidae] **[48]**
	sao den	*Trioza hopeae* Burckhardt & Vu [Hemiptera: *Sternorrhyncha: Triozidae]* **[61]**

[a] Voûte [96], citing Friederichs [95], mentions Chinese farmers at Tjilintjing in the vicinity of Batavia (Cilincing in Jakarta) managing O. smaragdina populations in mango trees to make it impossible for mango fruit weevil to lay eggs on trees. Eggs could only be found on trees not populated by the ant.

Macgowan [42, 43]: Dr Daniel Jerome Macgowan), citing an unidentified Chinese writer, briefly mentions the use of ants, one clearly O. smargadina, as 'insecticides' to protect orange trees in Guǎngdōng from the devastation of 'worm', the collecting rearing and marketing of ants, and use of bamboo poles to facilitate movement of ants between trees. This information has been cited by several authors including, McCook [44], Anon. [45], and Huang [40]. Groff and Howard [41] and Swingle [46] recorded its use in 1918 to control the litchi stink bug (Tessaratoma papillosa (Drury) [Hemiptera: Pentatomomorpha: Tessaratomidae]) on litchi near Guǎngzhōu in China, and mention use of the silkworm (Bombyx mori (L.) [Lepidoptera: Bombycidae]) larvae to rear it. He (Hoffmann) and Zhou [14] mentions it use in citrus orchards for the control of caterpillars, stink bugs, and other harmful insects. Gressitt [47] recorded it use to suppress damage by destructive longhorned beetle borers in citrus orchards on Hénán (Honan in Wade-Giles) Island in Guǎngzhōu in the Pearl River Delta of Guǎngdōng. The island, now Hǎizhū District, was also known as Honam and Honglok.

Groff and Howard [41] questioned the value of O. smaragdina in the management of citrus pests noting that its usefulness appeared be related to destruction of caterpillars and other large insects, ‘as it did not destroy scale insects and not always plant lice’ (presumably Aphis aurantii Boyer de Fonscolombe and or Aphis citricidus (Kirkaldy)) [Hemiptera: Sternorrhyncha: Aphididae], that ‘are also serious enemies of citrus trees’. Nests were usually full of soft-scale insects that adult O. smaragdina had tended for honeydew. However, Groff and Howard [41] noted, during observations of citrus trees at the Canton Christian College (now Sun Yatsen University/Zhōngshān Dàxué) in Guǎngzhōu, that adult ants never seemed to tend the aphids, and that when the aphids were placed near a nest the ants initially were aggressive towards the moving bodies of the aphids. The ants then seized the aphids with their jaws and dropped them off the trees. They never seemed to tend the aphids, but colonies of soft scales were carefully tended and their excretions eaten. One observation seemed to indicate that aphids may be preserved by the ants under some circumstances. These observations were undertaken more than 10 years before D. citri was first recorded in mainland China. Van Mele et al. [48] and Offenberg et al. [49] mention O. smaragdina controlling populations of Aph. aurantii and Aph. citricidus. However, it is not clear if the ant killed the aphids, dislodged, deterred, or repelled these aphids, or whether low populations of the aphids in the presence of the ant were related to effective biological control by their parasitoids and predation by coccinellids, lacewings, and spiders in orchards where synthetic pesticide use is negligible. The ant feeds on honeydew produced by the aphids and other trophobionts including coccids, mealybugs, and margarodids.[50, 51]) The risk of trophobionts associated with the ant being considered significant pests is considered minimal.[28, 52, 53]

In short-term studies in late spring and summer Chen [52] assessed the impact of O. smaragdina on a range of insect pests in a citrus orchard at Huángtián (23.4203°N, 112.5363°E) ca 80 km WNW of Guǎngzhōu, where the ant was present at variable densities on trees and variably distributed within trees. Incidence of citrus stink bug (Rhynchocoris poseidon Kirkaldy syn. Rhynchocoris humeralis (Thunberg) [Hemiptera: Pentatomomorpha: Pentatomidae]) damage (fallen fruit) was significantly reduced when the ant was sufficiently abundant. Damage related to other pests known to be controlled by the ant was less effectively suppressed. Populations of trophobionts such as citriculus mealybug (Pseudococcus cryptus Hempel syn. P. citriculus Green [Hemiptera: Sternorrhyncha: Pseudococcidae]), soft scales (Coccus spp. [Hemiptera: Sternorrhyncha: Coccidae]) and cottony cushion scale (Icerya purchasi Maskell [Hemiptera: Sternorrhyncha: Monophlebidae]) were not affected, nor were cerembycid larvae and a moth bug, Lawana sp. [Hemiptera: Auchenorrhyncha: Flatidae], or natural other natural enemies of pests. Variable beneficial impacts on reducing damage by pests, and costs and challenges of maintaining ant populations in orchards led to the conclusion that the ant was not an ideal natural enemy.

In orchards in Sìhuì county northwest of Guǎngzhōu, Yang [54] noted that R. humeralis was the most effectively controlled of 10 citrus pests effected by O. smaragdina in orchards. He also mentioned that farmers applied plant ash to tree trunks during the dry season or constructed water barriers at the base of trunks to prevent the ants moving from trees to the ground. Mealybugs in these orchards were parasitised by several parasitoid species, and ladybirds, spiders and green lacewings commonly existed on trees.[54]

Before 1960 farmers in Guǎngdōng applied 1–2 sprays annually to control citrus flea beetle, Clitea metallica Chen [Coleoptera: Chrysomelidae].[28]) The farmers relied on O. smaragdina to control other pests and, under such circumstances, D. citri was not regarded as a serious pest. Increased use of synthetic pesticides after 1960 led to sprays being required annually for control of the psyllid, citrus red mite (Panonychus citri (McGregor) [Acari: Tetranychidae]), citrus rust mite (Phyllocoptruta oleivora (Ashmead) [Acari: Eriophyidae]), aphids, and R. humeralis. In many orchards, scale insects, whiteflies, and leafrollers also became serious pests. Chen et al. [55] attributed ‘rampancy’ of citrus red mite after the 1960s to the increased use of synthetic pesticides. It is now a citrus important pest in China.[56]

In a field experiment at South China Agricultural University in Guǎngzhōu over five years from 1979, Chen [28] planted 55 sweet orange seedings in two blocks at Wàndòng (万垌, 23.4086°N, 112.5427°E), ca. 80 km WNW of Guǎngzhōu, after the seedlings were heated at 49°C for 50 minutes to kill ‘Clas’ and arthropods. Pests and natural enemies entered the blocks naturally from citrus trees adjacent to the experiment. Trees in one block were maintained under natural control and insecticides were applied 12–18 times annually in the second block. Incidences of 22 pests, which included R. humeralis, Pa. citri, Ph. oleivora, D. citri, Aph. aurantii, Aph. citricola, I. purchasi, a mealybug, a mosquito bug, a fruit spotting bug, a leafroller, a shoot caterpillar, two whiteflies, four amroured scales, two cerambycid borers, three leaf rollers, a butterfly, and citrus leafminer (Phyllocnistis citrella Stainton [Lepidoptera: Gracillariidae]) in the block of trees under natural control, were, aside from Ph. oleivora, low and HLB was not detected. D. citri was not regarded as a serious pest and survival from oviposition to eclosion of adults was < 1%. The incidence of the pests on the trees sprayed with insecticides was higher than on those under natural control and HLB was present. Survival of D. citri from oviposition to eclosion of adults over 18 generations ranged from 2.2–17.5%.[28] The low survival rate of D. citri under natural control suggests that O. smaragdina may have preyed on eggs and nymphs or removed them from plant surfaces, and thus contributed to mortality beyond that caused by primary parasitoids (Tamarixia radiata (Waterston) [Hymenoptera: Eulophidae]) and Diaphorencyrtus aligarhensis (Shafee, Alam & Agarwal) [Hymenoptera: Encyrtidae]) and predation by coccinellids, lacewings and spiders.

Chevalier [57] summarised observations by Eugène Poilane related to the breeding of O. smaragdina in Indochina for the defense of orange trees in Bến Tre (10.2442°N, 106.3754°E) in the Mekong Delta of southern Việtnam. A mandarin and orange orchard visited by Poilane was remarkably well-kept, each year producing very beautiful fruit. According to the farmer, it was essential to breed and maintain the presence of the ant, and to use wires to provide a connecting medium between trees for easy movement in order to make ‘war against bugs and moths that would bite the fruit (and also probably the orange tree fly)’, the latter, it seems, Oriental fruit fly, Bactrocera dorsalis (Hendel) (B. invadens Drew, Tsuruta & White) [Diptera: Tephritidae]: ‘Cette fourmi fait la guerre aux punaises et aux papillons nocturnes qui viendraient piquer les fruits (et aussi probablement à la Mouche de l'Oranger)’. Poilane believed that the ant plays protected fruit not only by attacking pests, but the odor given off by the ants was often enough to ward off biting insects.[57]. Poilane [58] mentions use of the ant to kill cerembycid borer larve and to protect fruit from ravages of the ‘Mouche de l'Oranger’. Farmers said that fruit quality was poor and spongy, without the ant.[58] During pest and disease surveys in 1990 and 1991, Whittle [59] noted that backyard citrus trees in the Mekong Delta in southern Việtnam were practically free of foliar pests, largely because of O. smaragdina.

Van Mele & Cúc (Nguyễn) [60] reported that pesticide use can be halved when the ant, known as kiến vàng in Vietnamese, is present in citrus orchards in the Mekong Delta. Despite these reports and that of Chen [28], it is not fully evident how O. smaragdina suppresses populations of D. citri. Worker ants move rapidly within citrus tree canopies, including immature flush suitable for oviposition and nymphal development (pers. obs). Nguyễn (Cúc) et al. [61] reported experiments and surveys related to ant activity, ACP populations, and HLB incidence in orchards in the same region. The ant reduced populations of the psyllid and the incidence of HLB to low levels in the Delta (Table 2), and the extent ant activity was related to the abundance of the psyllid in trees (Table 3). Nguyễn (Cúc) et al. [61] recorded O. smaragdina preying on eggs in laboratory studies (Table 4) but did not mention it removing or preying on nymphs and adults in orchards. But it may: Vu et al. [62] observed it feeding on, and also eggs and nymphs removal of, Trioza hopeae Burckhardt & Vu [Triozidae] on ‘sao den’ (Hopea odorata Roxb. [Malvales: Dipterocarpaceae]) in southern Việtnam. This led to very few or no galls being formed on immature leaves of the host.

Table 2. Trees expressing symptoms of HLB in the presence or absence of *Oecophylla smaragdina* in Mekong Delta orchards: translated from Nguyễn (Cúc) et al. **[61]**

Number of orchards	Pesticide sprays	Incidence of *Oecophylla smaragdina*		HLB symptoms (rating 0–5)	
		trees with ants	ants/tree/5 min	mean	range
10	common	none	0	4.3	2–5
6	common	< 50%	< 20	2	2
6	none	80–100%	> 30	0.3	0–1

Table 3. Impact of *Oecophylla smaragdina* activity on *Diaphorina citri* on citrus trees in a Mekong Delta citrus orchard: translated from Nguyễn (Cúc) et al. **[61]**

Number of trees	Ants/tree/5 min	Mean number of *Diaphorina citri*/tree
30	0	10.56
30	> 30	0.36

Table 4. Decline in *Diaphorina citri* (eggs and first and second instar larvae) 24 and 48 h after release of *Oecophylla smaragdina* adults in laboratory studies: summary of two experiments translated from Nguyễn (Cúc) et al. **[61]**

Duration of observations (hours)	Replicates	Ants per replicate	Mean number (range) of *Diaphorina citri*		Percent decline
			before ants released	after ants released	
24	8	20–25	18.8 (15–20)	7.0 (0–15)	62.7
48	9	30–50	35.7 (21–69)	16.7 (4–37)	53.3

It is possible that abdominal Dufour's gland secretions **[63, 64]** deposited as ant trails by *O. smaragdina* workers on plant surfaces may repel *D. citri* adults. The secretions, which are produced by both *O. longinoda* and *O. smaragdina*, persist on plant surfaces for extended periods. Deposits produced by *O. longinoda* can be detected by workers 11 months after they have been deposited.**[65]** Offenberg [66] proposed that deposit persistence and coverage throughout the ant territory could provide reliable cues about ant presence and predation risk and, therefore, alert potential prey.. Van Mele et al. **[35]** reported that female *B. dorsalis* are reluctant to land on fruits exposed to abdominal Dufour gland secretions of *O. longinoda*, and that after landing female flies frequently take-off quickly and fail to oviposit. Secretions of *O. smaragdina* are known to also repel pollinators.**[67, 68]**

Weaver ants bite humans and will attack if teased or disturbed.[41]. Risk of being bitten in orchards can be readily addressed by enticing ants out of orchards when access to trees is required and by application of wood ash to exposed limbs.[69]. Use of the ant in biological control is compatible with other natural enemies and of minor concern with respect to attendance of honeydew-producing soft scales and mealybugs.[53] Use with mineral oils is also compatible.[27, 70, 71] Most recent research on the use of Oecophylla species in biological control of pests of tree crops has been in Africa and in southern Việtnam.[72] There is a clear need for O. smaragdina to be extensively evaluated for use in conjunction with other natural enemies to suppress populations of D. citri and incidence of HLB. It could be used in environments where the ant occurs naturally and where it can be cultivated, nurtured, and managed within orchards. Van Itterbeeck [73] discussed prospects for semi-cultivating the ant. It is reared artificially on a small scale in Yogyakarta as food for feeding the Sunda pangolin (Manis javanica Desmarest [Pholidota: Manidae]) [74]: see also https://www.youtube.com/watch?v=YytL0rIGi4s.

Research is required to empirically demonstrate that O. smaragdina secretions repel D. citri and, if so, which of the known constituent molecules in the secretions affect psyllid behaviour, alone or in specific proportions, and whether the compounds can be incorporated in sprays applied in orchards to suppress psyllid populations. Repellent effects of mineral oils on D. citri [75-77] may be related to mimicry of the O. smaragdina secretions, as has been postulated for responses of Bactrocera tryoni (Froggatt) to deposits of horticultural and agricultural mineral oils.[78] The cost-effectiveness of mass-rearing O. smaragdina for biological control of insect pests in orchards, including D. citri on citrus trees, and for medicinal uses, food (animals and humans) and beverages should be determined.

4. Conclusion

Oecophylla smaragdina should be extensively evaluated in Asia for suppressing incidence of HLB in both small family/village orchards, as in the Mekong Delta, and in larger commercial orchards. As noted by Van Mele et al. [48], Biological control practices with predatory ants O. smaragdina are not limited to traditional small-scale farming systems but also on large plantations as they play a key role in reducing the incidence of major insect pests in commercial cashew plantations in Northern Australia, where it is also an important component of the program. IPM in mango garden.[71, 79-83] Use of synthetic insecticides is not sustainable and their use has not prevented devastating consequences of HLB.

The following leaflet and videos are recommended:

- https://assets.accessagriculture.org/upload/files/Access_Agriculture_leaflet_2021_ENGLISH.pdf
- https://www.accessagriculture.org/weaver-ants-against-fruit-flies
- https://www.accessagriculture.org/promoting-weaver-ants-your-orchard
- https://www.tapatalk.com/groups/antfarm/journal-of-oecophylla-smaragdina-a-k-a-asian-weave-t18173-s20.html
- https://www.youtube.com/watch?v=S2Zz3YRJPDY
- https://vtv.vn/video/chao-buoi-sang-23-7-2021-511815.htm?fbclid=IwAR06Nk72j3Eb6ZPjm-A9N_qhQW_vSUkLOI-WXWRyApGfBRbvgKuEJ0DHwRs. (Three minutes from 15.00 to 18.00 minutes)

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