

Identification of Whitefly Species (Hemiptera: Aleyrodidae) Invaded Coconut Palms in Sri Lanka

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Abstract

The current whitefly invasion is becoming a growing threat to coconut palms in Sri Lanka and will severely influence coconut production in the country. To effectively manage this problem, it is crucial to identify the specific species that have invaded the coconut palms in the country to accordingly provide appropriate solutions. The taxonomy of the whitefly is mainly based on the characters of the pupae. Thus, a field survey was conducted in 2023 to identify the key whitefly species that invaded the coconut palms and their host range in Sri Lanka. The colonies of infested whiteflies were collected from coconut palms in different coconut-growing areas of Sri Lanka, and the pupae were slide-mounted and identified up to species level using taxonomic keys. Further, diagnostic characters of each species and host range were documented. The whitefly species found on the coconut palms (*Cocos nucifera*) were identified as *Aleurodicus rugioperculatus*, *Aleurodicus dispersus*, and *Aleurotrachelus atratus*. *A. atratus* was discovered only from the *C. nucifera*. *A. dispersus* and *A. rugioperculatus* were reported from 5 and 24 host plant species including the coconut from 5 and 18 different families respectively.

Keywords: Aleyrodidae, invasive species, rugose spiralling whitefly

Introduction

The introduction of exotic pests and diseases always badly influences to the agricultural economy in the world. Among the insect pests reported, whiteflies (Hemiptera: Aleyrodidae) are considered as economically important, most destructive pests causing direct losses to agricultural cultivations. So far, there are about 1562 species of whiteflies reported throughout the world (Ouvrard and Martin, 2019). Currently, Sri Lanka has experienced a concerning

invasion of coconut whiteflies. It is causing damage to coconut palms, leading to yield reduction and increased cost of production due to the requirement of more insecticide application for the management of the pest. The whitefly infestation has already been reported in various coconut-growing areas including western, southern, and north-western provinces in the country. Sri Lanka ranks as the fourth-largest coconut producer in the world, and the agrarian economy of the country is greatly impacted by the substantial contribution from this sector. It provides food security and livelihoods for about 0.7 million people in Sri Lanka, covering over 1 million hectares and generates approximately Rs.175.000 ha⁻¹ annually (Ceylon Exports & Trading Sri Lanka, 2021). The favourable tropical climatic conditions, fertile soil, and extensive coconut lands in the country facilitate the production of high-quality coconuts and associated products. However, present whitefly invasion and establishment will pose a significant threat to the coconut industry in the country. Therefore, it is crucial to promptly implement measures to control this problem.

Whiteflies (Hemiptera: Aleyrodidae) are small, white colour, soft-bodied polyphagous insects. Both nymphs and adults usually possess a wax layer released through abdominal glands. Since the appearance and pattern of wax layers differ among species, they can be used for the identification purpose (Botha et al., 2000). Generally, white waxy substances appear on the underside of the infested leaves. The whitefly sucks the sap from the plant, which weakens the plant and hampers plant growth by losing its water and nutrients. Therefore, it shows chlorosis of the leaves and irregular yellowing patches on the leaf tissues. Further, during the feeding period whitefly injects toxins into plant tissues (Watson, 2007); causing wilting, stunting, and even death of its host plants (Botha et al., 2000). A sticky honey-like solution; honeydew is excreted by the whitefly accumulated on the surface of the leaves which facilitates the growth of black fungus (sooty mold) and badly influences

to the photosynthetic efficiency of the tree (Francis et al., 2016). In severe damage, leaf shedding can be observed and decreased the productivity of the plants. In addition, they play the role as vectors for some plant viruses (Byrne et al., 1990; Hodges and Evans, 2005).

According to the literature, there are at least 49 species of whitefly reported in Sri Lanka (David, 1993). However, the number of whitefly species in Sri Lanka should far exceed this number. Further, literature on whitefly species that currently threaten the coconut palms in Sri Lanka is still limited. Therefore, research on the existing whitefly species is essential in order to identify exotic and invasive whiteflies. It is considered that different pest species vary in their susceptibility to control measures as well as the level of damage they can inflict. Therefore, it is important to identify which species infested the coconut palms of Sri Lanka to provide appropriate recommendations to manage the current havoc of whitefly. Furthermore, information related to the host range is also required as information to support the success of control measures. Therefore, this study updates the species taxonomy, damage, and host range of whiteflies that invaded in coconut palms in Sri Lanka.

Methodology

A survey was carried out to collect different life stages of the whiteflies from randomly selected coconut palms in different coconut-growing areas in Sri Lanka during January -April months in 2023. During the sampling period, country was experienced the north-east monsoon and first inter monsoon seasons. The sampling locations represent different agro-ecological zones with different rainfall and temperature regimes. The mean annual temperature varied between 26 °C-28 °C in the lowlands and mean annual rainfall varied from under 900 mm in the south-eastern and north-western parts while over 5000 mm in the central highlands.

'Puparia' of whiteflies with pieces of coconut leaves were collected into polythene bags and taken to the Entomology Laboratory, Faculty of Agriculture, Rajarata University of Sri Lanka for slide preparation and identification. The methods described by Dubey and David (2012); Sirisena et al. (2013) were used for the permanent slide preparation of the collected specimens. Generally, final immature stage (Pupa) is used for the identification process of whiteflies. The slide preparation procedure involves several steps including maceration, bleaching (for black pupae), acidification, dehydration, de-waxing, clearing and mounting. For the maceration step, the puparial cases

were placed in 10% potassium hydroxide (KOH) with the purpose of removing waxy material and body contents and making the specimen transparent. Then, the specimens were soaked in distilled water to remove KOH. The specimens were acidified by transferring them to 80% ethyl alcohol prior to the staining using Acid fuchsin stain. The excess stain was removed by immersing the specimens in 80% ethyl alcohol. 95% ethyl alcohol was used to fix the stain and dehydrate the specimen. Any traces of lipids existing in the specimen were removed by dipping the specimen in histoclear phenol following 95% ethyl alcohol. Clove oil was used for further clearing of specimen. The specimens were mounted on glass slides using Canada balsam as the mounting media. Prepared slides were observed under a light microscope and species were identified based on the morphological characters of the pupal exuviae described in the literature (Martin, 1985; Martin, 1987; Martin, 1988; Martin et al., 2000; Hodges and Evans, 2005; Dooley, 2006; Watson, 2007).

Other host plants that infested by same whiteflies surrounding infested coconut palms were also recorded as the host range of these infested whiteflies. Photographs of whitefly specimens were taken to capture the detailed morphological characteristics of whitefly for the purpose of developing taxonomic descriptions.

Materials

Aleurodicus rugioperculatus

Study materials are five Sri Lanka's colonies from Ahangama (N 5°58'24.42, E 80°21'43.46064), 15.ii.2023; three colonies, Anuradhapura (N 8°22'17.832, E 80°25'20.772), 25.i.2023; two colonies, Dambadeniya (N 7°22'9.91488, 80°8'43.71036), 21.ii.2023; one colony, Dodanduwa (N 6°6'2.21158, E 80°7'40.87351), 16.ii.2023; one colony, Giriulla (N 7°20'24.70704, E 80°7'55.506), 21.ii.2023; one colony, Katupotha (N 7°33' 9.89784, E 80°11'30.71544), 30.ii.2023; one colony, Kosgoda (N 6°21'17.22295, E 80°1'7.31379), 18.iii.2013; two colonies, Rathgama (N 6°5'29.6306, E 80°8'37.23652), 16.ii.2023; one colony, Marawila (N 7°26'6.97917, E 79°49'16.3617), 26.iii.2023; two colonies, Mirigama (N 7°19'17.79384, E 80°7'16.03704), 7.iii.2023; one colony, Mirissa (N 5°57'15.35796, E 80°27'3.25764), 15.ii.2023; one colony, Narammala (N 7°25'17.04756, E 80°12'40.1814), 21.ii.2023; two colonies, Weligama (N 5°58'1.866, E 80°25'22.16352), 15.ii.2023.

Origin and distribution

It is believed that rugose spiraling whitefly (RSW) has been originated during 2004 in Central America (Belize) (Martin, 2004) and it was later reported in Mexico, Guatemala, and Florida in Central and North America (Evans, 2008) and subsequently it has spread to 22 other countries including India by 2016 (Selvaraj et al., 2016; Poorani and Thanigairaj, 2019; Visalakshi et al., 2021).

Aleurodicus dispersus

Study materials are one Sri Lanka's colony from Ahangama (N 5°57'54.1998, E 80°23'45.4578), 15.ii.2023; one colony, Anuradhapura (N 8°22'17.832, E 80°25'20.772), 25.i.2023; one colony, Galle (N 6°4'36.56757, E 80°10'45.2153), 15.ii.2023; one colony, Hikkaduwa (N 6°6'50.61097, E 80°7'25.80299), 16.ii.2023.

Origin and distribution

The spiralling whitefly, *Aleurodicus dispersus* is of Neotropical origin and native to Caribbean Region and Central America. This insect has expanded

its range towards the western direction across the Pacific Ocean and has now reached Southeast Asia. Additionally, the whitefly has been observed in Brazil, Ecuador, and Peru within South America, as reported by Waterhouse and Norris in 1989. Later, this insect has discovered in the Pacific and numerous Afrotropical countries (Akinlosotu et al., 1993; Legg et al., 2003; Mware, 2010), northern Australia, and Asian countries such as the Philippines, Thailand, India, Bangladesh, Indonesia, China, and even Sri Lanka (Wijesekera and Kudagamage, 1990; Kajita et al., 1991; Yu et al., 2007).

Aleurotrachelus atratus

Study materials are one Sri Lanka's colony from Gampaha (N 6°56'51.75647, E 80°3'20.16763), 7.iii.2023; Madampe (N 7°30'23.29625, E 79°53'5.37434), 20.iii.2023; two colonies, Habaraduwa (N 5°99'573, E 80°17'44.43693), 15.ii.2023.

Origin and distribution

Aleurotrachelus atratus (Palm-infesting whitefly) is native to the neotropical region that was originally

Table 1. Diagnostic key differences of the whiteflies infesting coconut palms (field and microscopic characters based upon the characters found in adult and puparium)

Character	Whitefly species		
	<i>Aleurotrachelus atratus</i>	<i>Aleurodicus rugioperculatus</i>	<i>Aleurodicus dispersus</i>
a. Field Characters			
Adult wing	Roof-like wings with no markings	Presence of a pair of irregular light brown bands across the wings	No markings on wing
Pupae	Black cuticle covered with long marginal white wax fringe and dorsal wax filaments	Single broader fluff at the posterior end	Two prominent fluff tail-like structures the posterior end
b. Microscopic characters			
Margin	Dentate margin	Crenulated margin	Crenulated margin
Terminal appendage of the legs	Adhesion pads	Claws	Claws
Corrugation in operculum	No corrugation in operculum	Corrugation in operculum	No corrugation in operculum
Compound pores	Absent	Smaller compound pores VII and VIII segments	Compound pores with a dagger like process Compound pores absent in VII and VIII segments.
Lingula	Rounded lingual apex	Triangular shape with acute apex	Tongue-like blunt lingula

described in the Brazil (Mound and Halsey, 1978) and later it disseminated into Palaearctic region (Canary Islands), the Pacific region Africa, the Malagasian region (Comoros Islands), North and South America, Central America and the Caribbean, Europe, and Oceania (Evans, 2007). It was reported that the occurrence of *A. atratus* in India by Selvaraj et al. in 2019.

Results and Discussion

The whitefly species found on the palms (*C. nucifera*) were identified as *Aleurodicus rugioperculatus*, *Aleurodicus dispersus*, and *Aleurotrachelus atratus*.

Aleurodicus rugioperculatus Species Identification

Genus *Aleurodicus* Douglas (1892) was raised by Douglas (1892) with *Aleurodicus annonae* Morgan as the type species. *Aleurodicus* is widespread with

86 described species and primarily native to the Neotropical region, however, few species are native to the Asia-Pacific region (Martin, 1996).

Diagnosis of this genera includes legs that are oriented towards the midline and large and distinct terminal claws are always present on the legs (Figure 1B). Long antennae curved and extended to the region of the middle leg or hind leg (Figure 1B). There are four to six pairs of abdominal compound pores comprised of central processes, located in the sub-dorsal area (Figure 1 & 2). Usually, the first four compound pores are large and evenly located on segments III-VI (Figure 1E). The central processes of the compound pores exert beyond the pore orifice (Figure 1E). Additionally, one or two smaller compound pores are present (Figure 1F) or absent on caudal segments VII and/or VIII. Discoidal, wide-rimmed, double-rimmed, and septate shape simple pores may present or absent within this genus (Figure

Table 2. List of whitefly species and their host range recorded during the study

No	Species	Common name	Scientific name	Family
1	<i>Aleurotrachelus atratus</i>	Coconut	<i>Cocos nucifera</i>	Arecaceae
		Coconut	<i>Cocos nucifera</i>	Arecaceae
		Hummingbird tree	<i>Sesbania grandiflora</i>	Fabaceae
2	<i>Aleurodicus dispersus</i>	Banana	<i>Musa</i> sp.	Musaceae
		Eggplant	<i>Solanum melongena</i>	Solanaceae
		Pepper	<i>Piper nigrum</i>	Piperaceae
		Coconut	<i>Cocos nucifera</i>	Arecaceae
		Arecanut	<i>Areca catechu</i>	Palmae
		Avocado	<i>Persea Americana</i>	Lauraceae
		Banana	<i>Musa</i> sp.	Musaceae
		Breadfruit	<i>Artocarpus altilis</i>	moracea
		Cashew	<i>Anacardium occidentale</i>	Anacardiaceae
		Chillie	<i>Capsicum annuum</i>	Solanaceae
		Citrus	<i>Citrus</i> sp.	Rutaceae
		Coffee	<i>Coffea arabica</i>	Rubiaceae
		Croton	<i>Codiaeum variegatum</i>	Euphorbiaceae
		Curry leaves	<i>Murraya koenigii</i>	Rutacea
		Eggplant	<i>Solanum melongena</i>	Solanaceae
		Guava	<i>Psidium guajava</i>	Myrtaceae
3	<i>Aleurodicus rugioperculatus</i>	Indian almond	<i>Terminalia catappa</i>	Combretaceae
		King coconut	<i>Cocos nucifera</i> var. <i>aurantiaca</i>	Arecaceae
		Kitul palm	<i>Caryota urens</i>	Arecaceae
		Long bean	<i>Phaseolus vulgaris</i>	Fabaceae
		Mango	<i>Mangifera indica</i>	Anacardiaceae
		Nerium	<i>Nerium oleander</i>	Apocynaceae
		Okra	<i>Abelmoschus esculentus</i>	Malvaceae
		Pepper	<i>Piper nigrum</i>	Piperaceae
		Downy Jasmine	<i>Jasminum multiflorum</i>	Oleaceae
		Watermelon	<i>Citrullus lanatus</i>	Cucurbitaceae
		Winged bean	<i>Psophocarpus tetragonolobus</i>	Fabaceae

2). The vasiform orifice is chordate (heart-shaped) and lingual is exerted beyond the vasiform orifice and consists of four setae (Figure 1G & 2C). Usually, sub margin possesses twelve pairs of setae including 2-4 submedian pairs of cephalathoracic setae and a pair of normal caudal setae (Figure 1C & 2D). Anterior marginal setae absent.

Aleurodicus rugioperculatus Martin, 2004 Species Identification

In terms of biology, *Aleurodicus rugioperculatus* is known as rugose spiraling whitefly (RSW) which is composed of six different developmental stages as eggs, three larval instars, pupae and adult stage. It is reported that the mean duration of the total life cycle is about 56 days including the egg stage (8 days), larval stage (17 days), pupal stage (10 days) and adult stage (20 days) (Kolanthasamy et al., 2021; Saranya et al., 2021). The eggs of RSW are about

0.3 mm long, elliptical shape, translucent and creamy yellow in colour (Figure 4C). Each egg has a short stalk and lays singly on the under surface of leaves in a spiral mode or a concentric pattern with covering of white waxy matter (Figure 4A). After the hatching out of eggs, nymphs are developed. These nymphs are light to golden yellow in colour and 1.1-1.5 mm long depending on the instars. Usually, they produce both dense tufts of fluffy and thin, long crystal-like wax filaments. The first instar also known as crawler stage is the only mobile immature stage that has functional legs and distinct antennae. First, they look around for a suited feeding place and suck the plant sap using its needle-like mouthparts. After the moulting of crawlers, immobile immature stages are developed. Initially, they are flat and oval shape and cream-coloured studded with white waxy material on the sides. With the progression of the life cycle, they become more convex. There is inconspicuous projection on the nymphs normally emerged as one

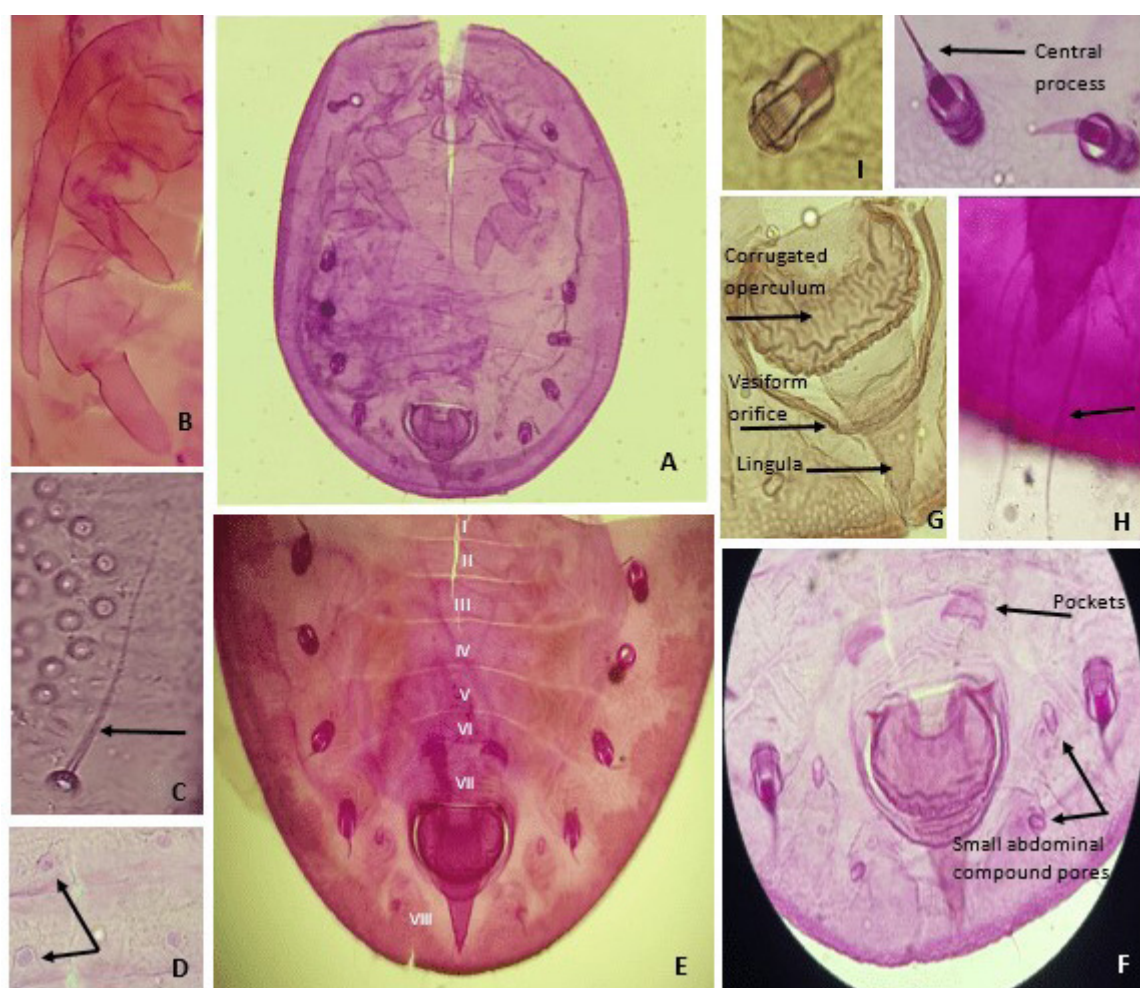


Figure 1. Diagnostic characters of a slide mounted pupae of *Aleurodicus rugioperculatus*: A, mounted puparium; B, antennae and thoracic legs with claws; C, submarginal setae; D, septate pores; E, abdominal segments; F, posterior dorsal area of the puparium; G, vasiform orifice, exerted triangular shape lingula and corrugated (wrinkled nature) operculum; H, lingula with 4 setae; I, large abdominal compound pores with dagger-like central process.

broader fluff tail-like structure on the posterior side. The last immature stage is the convex shape pupal stage (about 1 mm) (Figure 4D) used in taxonomic identification. Adults emerge from the pupae that show lethargic appearance and usually about three times larger (approx. 2.5 mm) than the common whiteflies (Figure E & F). The presence of a pair of irregular light brown mottling pattern across the wings and the large size of adults make them distinguished. Further, they possess greyish colour eyes and prominent glands on the ventral side through which the white flocculent wax matter emerges out. Adult males are slightly smaller than females and there is a long pincer-like structures at the distal end of their abdomen.

Identification Features of the Pupae

RSW pupae displayed the following characters: presence of distinct cephalic and anterior 4 pairs of abdominal compound pores, 2 pairs of much smaller pores present on abdominal segments VII and VIII (Figure 1E & F), with dagger-like process (Figure 1I), occurrence of broadly cordate vasiform orifice, presence of corrugation on the surface of operculum, presence of a finely spinulose, narrowly acute lingual apex, lingula head protruding beyond vasiform orifice (exserted lingula) (Figure 1G), its four setae situated close to the apex (Figure 1H), presence of posterior marginal, and 12 pairs of outer submarginal setae (including nominal caudal pair) (Figure 1C), absence of anterior marginal, cephalic and 1st abdominal setae, pro-, meso, and metathroacic single submedian pairs of setae and 8th abdominal setae situated fully anterior to vasiform orifice, presence of the zone of crowded, wide-rimmed pores at the submargin, forming inner boundary of zone with mesally-directed lobes, the pore band interrupted immediately posterior to lingular apex, occurrence of reticulated cuticle on dorsum (However, the body reticulation is varied according to the level of bleaching and within a species (Dubey et al., 2008)).

Host Plants

RSW has been known to attack about 118 hosts belonging to 43 families including cultivated crops and weed flora (Francis et al., 2016).

Nature of Damage and Economic Importance

The presence of heavy, white, waxy material and life stages of RSW occur on the underside of the leaves (Figure 5) as well as sucking the phloem sap from the host plants disrupts the normal leaf physiology (Dickey et al., 2015). In addition, they excrete large quantities of honeydew which covers any surface under the host plant. Profuse deposition of honeydew allows

the growth of black sooty mold fungus (*Capnodium* spp.) that interfere with the photosynthetic area of the leaves and thereby reduce the photosynthetic efficiency of the plant (Mayer et al., 2010; de Omena et al., 2012). Almost all host plants appear in brownish-black colour due to this secondary infection of sooty mold which is quite visible from a distance (Figure 5G). The type and level of damage can be varied according to the factors of the host plant such as species, and physiology conditions. However, plants are in unhealthier conditions may be vulnerable to death with very high infestation levels (Mayer et al., 2010; Ullah et al. 2021). RSW jeopardizes the coconut industry in the world by reducing coconut production, the quality of nuts, and increasing production costs for the management of the pest. Coconut palms (*C. nucifera*) are infected severely as they are cultivated as a monoculture in all tropical regions of the world (Howard, 2001).

Species Identification of *Aleurodicus dispersus* Russell, 1965

In terms of biology, *Aleurodicus dispersus* is composed of six different developmental stages as eggs, three larval stages, pupae and adult stage. It is reported that the mean duration of the total life cycle is about 22.5- 29.66 days including egg stage (5-8 days), larval stages (1st larvae- 2.15-6.5 days, 2nd larvae-2.7-5 days, 3rd larvae-2.9-5.96 days), pupal stage (10 days) and adult stage (14 days) (Geetha, 2000; Pradhan and Abhilasa, 2020). *A. dispersus* is also known as spiraling whitefly due to laying eggs in characteristic spiral mode and is covered with powdery wax material (Figure 4G). These eggs are 0.3 mm long, elliptic shape and tan-yellow colour with a short stalk. After hatching eggs, nymphs are developed. The 1st larval stage is the mobile stage known as “crawler” having functional legs and antennae. Further, it is about 0.4 mm long, yellow to green in colour, translucent, and elliptical shape with white powdery wax. The 2nd larval stage is about 0.5 mm long, translucent and oval shape with waxy marginal fringes. The 3rd larval stage is about 0.65 mm long. Further, it has short translucent waxy rods along the body. Pupae is 1.5 mm long, white in colour and convex in shape. There are prominent projections with two fluff tail-like structures on its body (Figure 4H). Initially dorsally flatten body surface becomes ventrally swollen. There are different amounts of white, waxy secretions extending upward and outward from the dorsum and glasslike waxy rods arising from each compound pore of the body. Generally, the adults emerge forming a “T” shape opening on the dorsum of pupae. Adults are slender, 2.1 mm long with pure white in colour, and there are no markings on their wings (Figure 4I).

Pupae Feature Identification Features

Pupae possess only four abdominal pairs of cylindrical shape compound pores that are decreasing in size from the third segment to the sixth segment, the last pair (on the 6th segment) slightly larger than the prothoracic pores with caudal pair of compound pores below the level of the vasiform orifice, absence of pairs of smaller compound pores on abdominal segment seven or eight (Figure 2A). Absence of corrugation in operculum, the occurrence of tongue-like oval shape, blunt lingual with 4 setae (Figure 2C). The dorsal margin possesses a single row of 8-shaped pores; the submargin has double-rimmed pores in a single row (Figure 2I); septate pores are present in most of the median and submedian abdominal area and below the vasiform orifice (Figure 2G). Septate pores are absent in the 1st abdominal segment, the median area of the 7th abdominal segment between pockets (1 rarely present), and from anterior to the 8th abdominal

segment. Wide-rimmed pores are distributed in a single row between the 8-shaped and the double-rimmed pores, and 1 or 2 deep between double-rimmed and septate pores (Figure 2E). Numerous minute wide-rimmed pores are present around (a few on the 7th and 8th abdominal segments). 11 pairs of setae on the submarginal area; caudal setae are located within a row of double-rimmed pores.

Nature of Damage and Economic Importance

The spiraling whitefly has a wide host range, encompassing 147 host plants in 53 families (Boopathi, 2013).

Like other whiteflies, *A. dispersus* is also directly damage to host plants by depleting plant sap which causes chlorosis, stunted growth, and potentially death of the plant with higher severity of the infection. At the same time, it indirectly affects to plants by

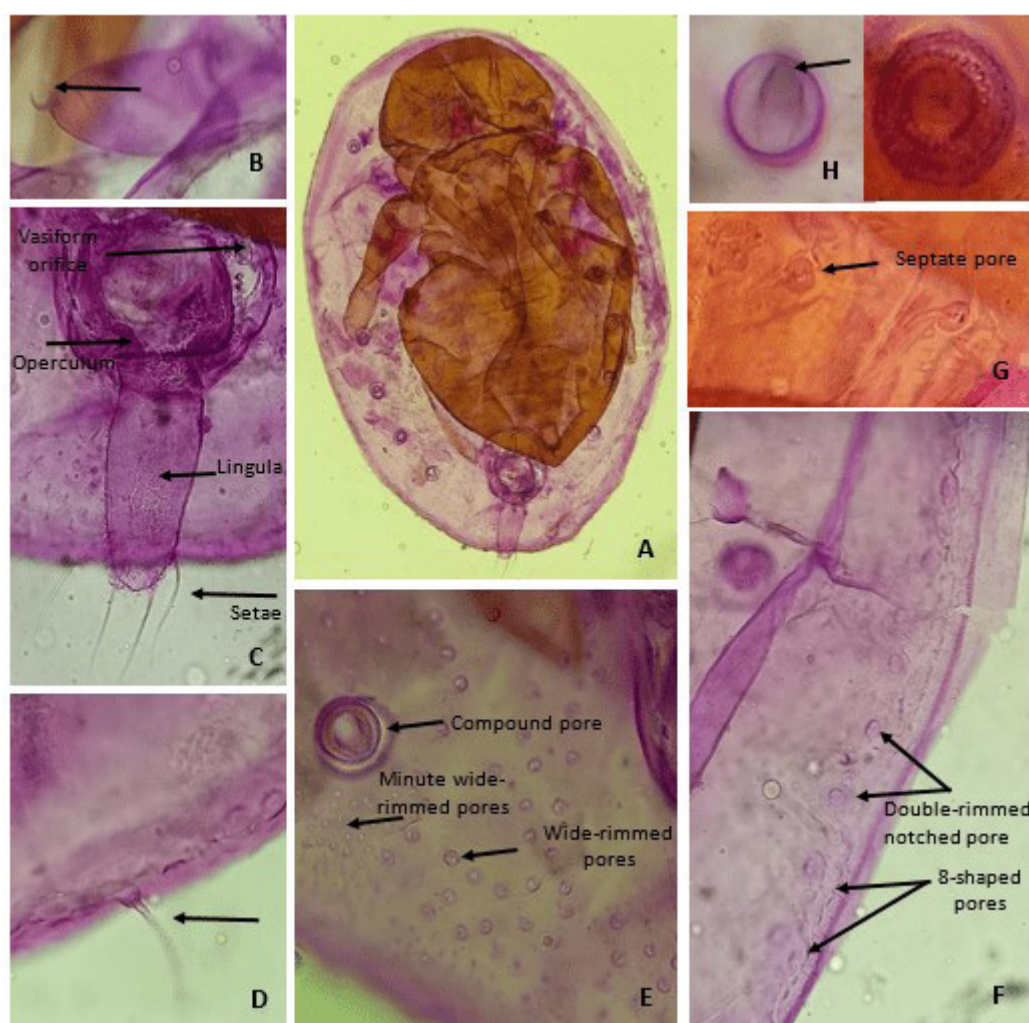


Figure 2. Diagnostic characters of a slide mounted pupae of *Aleurodicus dispersus*: A, mounted puparium; B, thoracic leg with terminal claw; C, exerted blunt lingula with 4 setae; D, caudal setae; E, sub-margin area with different simple pores; F, dorsal margin with rows of 8-shaped pores and double-rimmed notched pores; G, septate pores; H, compound pore with central process.

promoting the growth of sooty mold and producing waxy, filaments that can diminish plant photosynthetic efficiency and aesthetic value (Figure 5). It is reported that *A. dispersus* act as a vector of plant viral diseases, ex: cassava brown streak virus (CBSV), a Begomovirus, in Kenya (Berlinger, 1986; Mware, 2010). In addition to the coconut palms, it has been reported as a significant pest of pepper in Nigeria (Pitan, 2003), in India (Beevi and Lyla, 2001), and in Indonesia (Yuliani et al., 2005). In 1990, the spiraling whitefly has been reported in Sri Lanka, however at that time it is considered as a minor pest to coconut palms with compared to other crops (Wijesekera and Kudagamage, 1990). Infested planting materials and other plant-based trade as well as human movement are considered as the potential agents that ensure the long-distance transmission of *A. dispersus* (Asiwe et al., 2002).

Genus *Aleurotrachelus* Quaintance and Baker, 1914 Species Identification

This genus was raised by Quaintance and Baker in 1914. It is considered one of the largest genera of whiteflies and is currently comprised of 74 species (Martin and Mound, 2007).

Diagnosis of *A. dispersus* includes dark brown to black puparium possesses dentate margin which is appeared as a double row of teeth since presence of the glands at the base of the marginal teeth. Longitudinal fold is located on the cephalothorax of the

dorsum separating the dorsal disc. Rhachis present with or without arms. Subcircular or subchordate vasiform orifice is longer than the width. Lingula is obscured by the operculum or extended beyond the vasiform orifice. Cephalic setae present or absent. Setae on the abdominal segment one is thickened and located close to the median line, setae present on the caudal area and abdominal segment eight.

Morphological Identification of *Aleurotrachelus atratus* Hempel, 1922

The morphological identification of *Aleurotrachelus atratus* include their life stages that occur on the underside of the leaves. *Aleurotrachelus atratus* is composed of six different developmental stages as eggs, three nymphal stages, pupae and adult stage. It is reported that the mean duration of the total life cycle is about 48 days including egg stage (10 days), nymphal stages (1st instar- 6.5 days, 2nd instar- 6.8 days, 3rd instar- 9 days and pupal stage (15 days) and adult stage (14 days) (Borowiec et al., 2010). Elliptical, stalked eggs are in 0.2 mm length, initially creamy white and turn to dark brown before hatching. The first instar is comprised with four pairs of wax plumes excreted by wax glands at the base of dorsal setae. There are curved longitudinal grooves in each dorsal seta that guide the wax flakes. The body lengths of nymphs are 0.2 mm (1st instar), 0.3 mm (2nd instar), and 0.4 mm (3rd instar). All nymphs are black in colour and have eight prominent white spots which later coalesce and partially cover the black body. Elongated, oval shape and about 0.6 mm long puparium has an entire

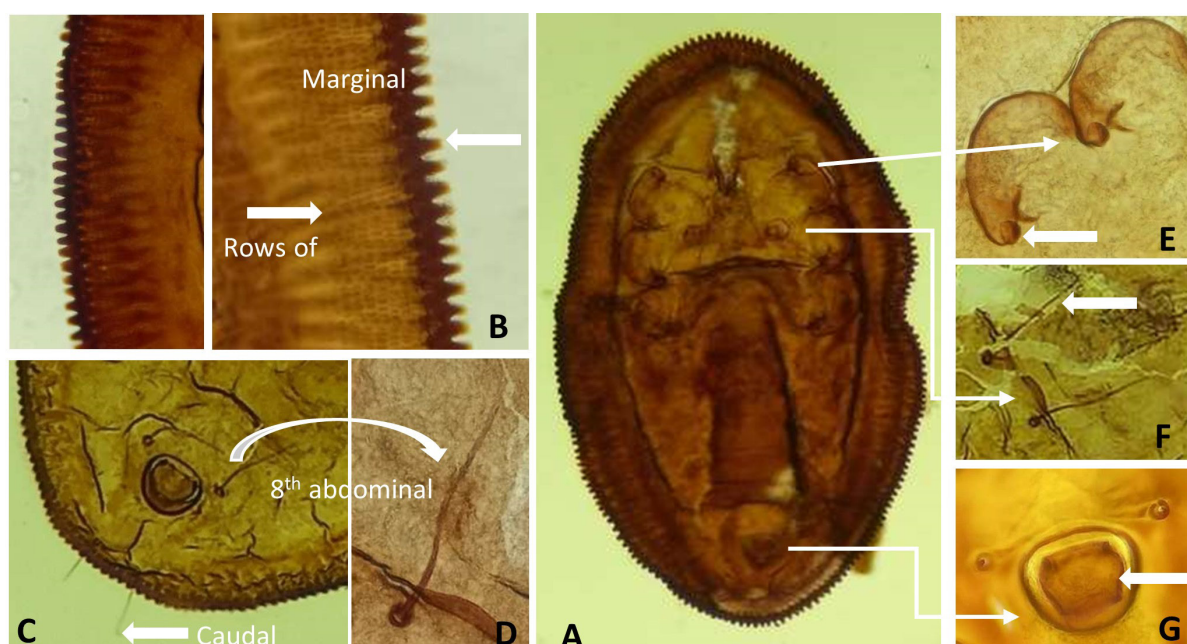


Figure 3. Some labels have been missed in the figure 3B and 3C. In the figure 3B- Marginal teeth, 3C & 3D-8th abdominal setae, 3C-Caudal setae

dark cuticle with a long marginal white wax fringe and dorsal wax filaments that often completely cover the insect (Figure 4J). When this dense flocculent white wax is removed, each puparium can be seen to have a distinct diagnostic pair of submarginal longitudinal cephalothoracic folds that extend into the abdomen (Figure 4K). Adults are about 3 mm long and have roof-like wings (Figure 4I).

Pupae Feature Identification

Marginal serrations occur on pupa, the lingual tip is rounded and not bilobed (Figure 3G), sub-marginal fold is interrupted at vasiform orifice. The marginal teeth are separated, with converging subtruncate or rounded apices and submarginal area with rows of flat, elongate granules of sub equal size (Figure 3B). The first abdominal and mesothoracic setae are absent, metathoracic setae extending beyond 2nd abdominal segment (Figure 3F), 8th abdominal setae longer than the vasiform orifice (Figure 3C & 3D), and



Figure 4. Different life stages of whiteflies on leaf surfaces: *Aleurodicus rugioperculatus* A, eggs laid in spiral mode; B, & C, eggs; D, pupae; E, colony; F, adult; *Aleurodicus dispersus* G, eggs in spiral mode; H, pupae; I, adult; *Aleurotrachelus atratus* J, nymph stage with wax filaments; K, pupae; L, adult.



Figure 5. Symptoms of damage of whiteflies to coconut and king coconut palms: A, infected young plant; B, numerous colonies on leaf; C, infected frond; D, infected fruit; E, & F, completely covered under surface of leaves; G, heavy growth of black sooty mold on leaves.

caudal setae very long and set on tubercles (Figure 3C).

Aleurotrachelus atratus has been discovered from 114 host plant species belong to five families and most (96%) of them represent the palms in family Arecaceae. Coconut is reported as the major host of *A. atratus* (Malumphy and Treseder, 2011).

Nature of Damage and Economic Importance

Aleurotrachelus atratus is a highly invasive pest of palms in tropical and subtropical regions and usually shows parthenogenetic reproduction (Borowiec et al., 2010). *A. atratus* is most economically significant as a pest of coconut; for instance, 90% of coconut palms were severely infested by the whiteflies *A. atratus* in Grand Comoro (Streito et al. 2004). The growth and productivity of coconut palms are significantly impacted by the negative effects caused by the development of sooty mold, which arises from the honeydew secreted by whiteflies. The palms are died because of the heavy whitefly infestations. *A. atratus* is potential pest that impact to the tourism by attacking many ornamental palms commonly planted in tourist areas, such as the Canary Islands and Seychelles (Borowiec et al., 2010). The adults are poor flies due to their small size and fragile nature, even though they are winged. Therefore, long-distance (international) dispersal is occurred by the trade of infested planting materials of ornamental palms (Evans, 2008).

Conclusion

The coconut palms (*C. nucifera*) recently invaded whiteflies in Sri Lanka were identified as *Aleurodicus rugioperculatus*, *Aleurodicus dispersus*, and *Aleurotrachelus atratus*. *A. atratus* was only discovered from the *C. nucifera*. Including the coconut, *A. dispersus* were reported from four host plant species belong to four different families while *A. rugioperculatus* were reported from 24 host plants in 18 families. The key to the mounted characters of whitefly species will be useful for effective management, damage assessment, as well as further research studies such as understanding the population dynamics and biosecurity measures.

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