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Spiralling whitefly and its management practices in the South Pacific. A review

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Abstract: A few species of whiteflies are considered a serious insect pest of vegetation and ornamental plants across many countries. The Spiralling whiteflies, *Aleurodicus dispersus* Russell has been recorded on many different plant species across countries. These whiteflies feed exclusively on leaves and have the ability to spread plant diseases. A great deal of research has been done on whiteflies in relation to which control methods would be most effective in pest management. The management of Spiralling whitefly in the South Pacific is heavily reliant on biological control (using the parasitic wasps, predators and entomopathogenic fungi). Other control methods include physical, botanical, and chemical to keep the whitefly population at lower levels. In this paper, an overview of Spiralling whiteflies and its management practices in the South Pacific will be reviewed.

1. Introduction

Spiralling whiteflies, *Aleurodicus dispersus* Russell, 1965 (*Hemiptera: Aleyrodidae*), are polyphagous pest of agricultural and horticultural crops in glasshouses and fields worldwide (Oliveira *et al.*, 2001; Mani and Krishnamoorthy, 2002; Stansly and Natwick, 2010). It is a native to the Caribbean region and Central America (Waterhouse and Norris, 1989). It was first noticed as a pest in Hawaii in 1978 and since then has spread to the Pacific islands and other continents (Kumashiro *et al.*, 1983; Waterhouse and Norris, 1989).

Whitefly adults and larvae feed on leaves, stems and fruits by inserting stylets into the plant. Some specific plants that are usually attacked include cassava, pepper, papaya, mango, eggplant, citrus, guava, banana, coconut, breadfruit, tropical almond, sea grape, paper bark and rose (Russell, 1965; Jayma *et al.*, 1993; Neuenschwander, 1994; Reddy, 2015). When the stylets are in the phloem, the whiteflies ingest large quantities of sap that contains a lot of sugar. They excrete the excess liquids and sugar which is called honeydew. The honeydew is deposited on leaves and fruits, fostering the growth of black sooty mould fungi and falling of premature leaves. In addition, these moulds influence the rate of photosynthesis and transpiration as it hinders the light penetration, vapour movement and exchange, leading plants to exhibit yellowish specks on leaves, to wilt or die off (McAuslane *et al.*, 2004; Al-Shareef, 2011; Reddy, 2015).

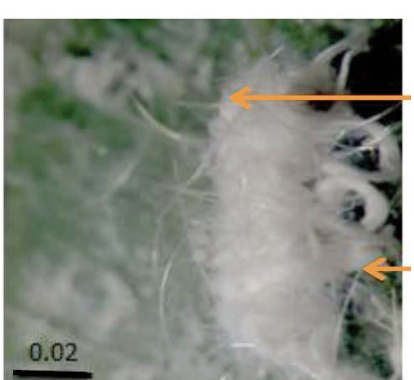
Spiralling whiteflies have caused detrimental effects in the production of crops and ornamental plants. It is one of the most common pest that has the ability to spread diseases and influence the global food production (ECPA, 2015). Over 300 plant species from approximately 77 families have been recorded as hosts of *A. Dispersus* worldwide (Lambkin, 1999). The spread of the Spiralling whitefly continues to increase rapidly due to the general ineffectiveness of chemical control and other pest control measures (Mani and Krishnamoorthy, 2002). Alternative measures for controlling Spiralling whiteflies include physical, cultural and biological control. These approaches have been used in the South Pacific but there is no data available (except biological control) that supports their practice and effectiveness in terms of whitefly management (Waterhouse and Norris, 1987). Hence, the present review builds information on studies carried in the South Pacific on *A. dispersus* Russell alternative control methods, which would be valuable in terms of effective management of the pest.

2. Origin, biology and whitefly-plant interactions

Aleurodicus dispersus is a tropical pest to a variety of horticultural crops, ornamental plants and shade trees (Department of Agriculture and Fisheries, 2015). It was first reported in Florida in late 1957 (native area being the Caribbean and Central America) and since then it has expanded its range to most regions around the world including North America, South America, Asia, Africa, Australia and several Pacific Islands (Russell, 1965; Waterhouse and Norris, 1987; Reddy, 2015). In the South Pacific, the pest has been reported in Majuro (1986) (Marshall Is), Cook Islands (1984), Fiji (1985), Nauru (1987), Papua New Guinea (1987), Kiribati (June 1988), Tokelau (late 1988) and Tonga (November 1988) (Waterhouse and Norris, 1987).

The lifecycle stages of *A. dispersus* are eggs, four larval instars and adults. The eggs (0.3 mm long) are usually smooth surfaced, yellow and tan elliptical in shape (Reddy, 2015). These are laid at an angle of 90° with Spiralling deposits of white flocculence on underside of the leaves. The first instars are mobile and called crawlers. They can travel to a short distance to select their feeding sites (Martin, 1987). They are usually 0.32 mm long and settle near the spiral pattern of the eggs from which they hatched. As the crawler grows, they develop mid-dorsal waxy tufts and the secretion of wax is usually from the narrow band of sub-margin. The second and third instars are 0.5-0.65 mm long and remains feeding at same place. The distinguishing feature about the third instar larvae is the presence of glass-like rods of wax (usually short and evenly-spaced) lined along the body. These cottony secretion is much less abundant than on the fourth instar [Russell (1965) cited in The Centre for Agriculture and Bioscience International (CABI, 2015)].

The fourth instar or puparium is 1.06 mm long and covered with numerous amounts of white materials and long glass-like rods (~8 mm in length); due to fragmentation some are shorter (Fig. 1). The second to fourth instars are protected by waxy secretions making them sessile and scale-like (Martin, 1987; Banjo, 2010). The adults are mobile and most active during the morning. The bodies of males are



Glassy wax rods emanating from each compound spores. These glassy rods are whitish in colour, translucent and longer (3-4 times) than the width of the body

From the dorusm (extending upwards and outwards) of mature puparium, a copious amount of white cottony substance is secreted

Fig. 1 - Mature puparium of Spiralling whitefly

usually 2.28 mm and females are usually 1.74 mm (3-4 times longer than the body width). The adults develop white translucent powder covering on their bodies. These whiteflies also have a pair of antenna. The males have several pores on the abdomen scattered dorsally, laterally and ventrally on the first 2 segments posterior to wax plates while the females are without pores [Russell (1965) cited in The Centre for Agriculture and Bioscience International (2015)]. The eye is reddish-brown in colour. The Spiralling whiteflies also have two characteristic dark spots on their forewings (Fig. 2). After mating adult females lay eggs in irregularly spiralling patterns and it is where whiteflies derived their common name, Spiralling whitefly (Reddy, 2015).

Heavy occasional rains and cool temperatures result in a temporary reduction in *A. dispersus* population (Mani, 2010). The mortality rate of immature stages increase between 40-45°C, and for adults the mortality rate increases at 35-40°C. Temperature below 10°C also lead to increased mortality (Cherry, 1979; Waterhouse and Norris, 1987). However, population of Spiralling whiteflies will increase during droughts and presumably when the natural enemies decline. The spread of crawler and winged adult whiteflies usually occurs with short-distance movements whereby the crawlers are walking on the plant on which it hatched and the plants that touch it and adults fly to other parts of the same plant or to other nearby host plants. Instead, the movement to long distance involves the international horticultural trade (Pacific Pests and Pathogens, 2016).

Whitefly-plant interactions - stomatal conductance

Whiteflies cause damage to plant productivity in terms of photosynthesis, respiration and transpiration performance (Shannag and Freihat, 2009). The whitefly *A. dispersus* is considered to be a major pest causing damages to crops (Boopathi *et al.*, 2015). These insect pests are reported to alter the chemical processes, growth and photosynthesis (Schröder *et al.*, 2005; Fatouros *et al.*, 2012). Moreover the plants primary metabolism is also altered by this particular infestation. For example, egg deposition by a particular species of moth (*Podoptera frugiperda)* demonstrated inhibitory effect towards the production of herbivore induced plant volatiles in maize plants (Fatouros *et al.*, 2012). The egg deposition has also shown to influence the rate of photosynthesis by reducing the amount of carbon dioxide diffusion in the mesophyll cells (Fig. 3) (Schröder *et al.*, 2005; Fatouros *et al.*, 2012). For instance, the study by Shannag and Freihat (2009) concluded that gas exchange in cucumber plants infested by whiteflies (*Bemisia tabaci*) caused photosynthesis to decline by up to 30%. The feeding behaviour of whiteflies also

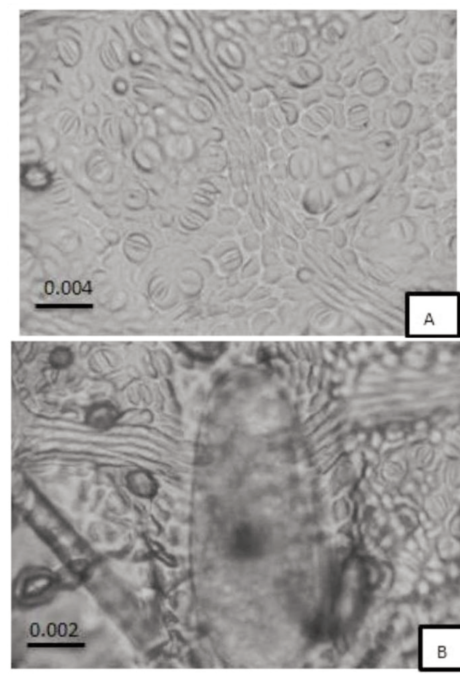


Fig. 3 - (A) the stomatal underneath the normal leaf surface and (B) the egg attached on the stomata of infected leaf.

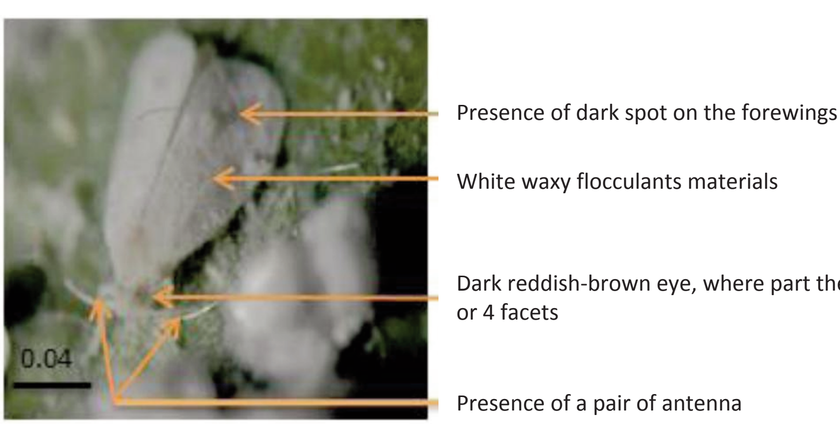


Fig. 2 - Adult of Spiralling whitefly.

increased the respiration rate by 24-78% and the rate of water loss from infested leaves was 3-32% greater than that of control leaves. Likewise, the increasing number of whiteflies (Tobacco whitefly) led to increase in transpiration rate (Shannag and Freihat, 2009). The artificial infestation of Spiralling whiteflies described by Pitan (2003) on pepper led to increase in the damage of leaves. This simply means that the chlorophyll, sugar, protein and crude fibre contents of the leaves decreased as with the level of infestation.

3. Status and damage in the South Pacific

The reproduction and dispersal rate of Spiralling whiteflies are relatively high, posing great threat to vegetable, tropical fruit tree and ornamental industries around the globe (Pacific Pests and Pathogens, 2016). The host range of these Spiralling whiteflies covers at least a range of 27 plant families, 38 genera and more than 100 species (Waterhouse and Norris, 1989). Despite there is no evidence in the measurement of economic loss by these Spiralling whiteflies in the South Pacific. Heavy infestations on plants is more likely to result in economic loss (Pacific Pests and Pathogens, 2016). Being a polyphagous, Spiralling whitefly has been recorded on many plant species in different countries. According to surveys conducted from 1996 to 1997 (Waterhouse and Norris, 1989; Barro *et al.*, 1997), Spiralling whitefly is an exotic pest in American Samoa, Cook Islands, Fiji, Kosrae (FSM), Pohnpei (FSM), Truk (FSM), Yap (FSM), Guam, Kiribati, Marshall Islands, Nauru, New Caledonia, Northern Mariana Islands, Palau, Papua New Guinea, Solomon Islands, French Polynesia, Tonga and Western Samoa (Table 1). The survey also revealed the absence of *A. dispersus* from Niue, Tuvalu and Vanuatu.

4. Management of *Aleurodicus dispersus* Russell

The management of whitefly has been difficult as a result of its many host plants. Perennial plants such as ornamentals, fruit trees and shade trees were probably used successfully throughout the year by this coloniser (whiteflies) which sucks the sap of leaves (Kajita *et al.*, 1991). According to Chandel *et al.* (2010), whiteflies must be dealt with a combination of environmental manipulations, natural enemy enhancement and area-wide control programme. This technique is known as Integrated Pest Management (IPM) which uses a combination of different strategies to control pests. The IPM program uses current, comprehensive information on the life cycles of pests and their interaction, combination with pest control methods to manage pest by the most economical means with least hazardous to the environment and the people (Boopathi, 2013; EPA, 2017). However, based on the literature available in the South Pacific, there are no reported studies on chemical and physical or combined (IPM) control practices on *A. dispersus*. The only data available is on biological control (Waterhouse and Norris, 1987). There are various methods of biological control of whitefly techniques utilised in the South Pacific, such as the use of parasitic wasps, predators (lacewings, big-eyed bugs and minute pirate bugs) and the use of entomopathogenic fungi of the genus *Aschersonia.*

Biological control

Natural predators and parasitoid. Spiralling whitefly is not regarded as a pest in its native area of Caribbean and Central America where it is assumed that populations are kept low by natural enemies (Prathapan, 1996). Biological control is perhaps the safest and most sound approach to pest control. It is an effective tool in programmes of Integrated Pest

Table 1 - Distribution of *Aleurodicus dispersus* whiteflies in the Pacific found during the whitefly survey (1996-1997)

Aleurodicus dispersus	AmS	CoI	Fij	Kos	Poh	Tru	Yap	Gua	Kir	MaI	Nau	Niu	NMI	Pal	PNG	SI	FrP	Ton	Tuv	Van	WSa
Distribution in 1996/7	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x			x
Exotic	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x			x
Serious Pest potential	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x			x

AmS= American Samoa; CoI= Cook Islands; Fij= Fiji; Kos= Kosrae (FSM); Poh= Pohnpei (FSM); Tru= Truk (FSM); Yap= Yap (FSM); Gua= Guam; Kir= Kiribati; MaI= Marshall Islands; Nau= Nauru; NCa= New Caledonia; Niu= Niue; NMI= Northern Mariana Islands; Pal= Palau; PNG= Papua New Guinea; SI= Solomon Islands; FrP= French Polynesia; Ton= Tonga; Tuv= Tuvalu, Van= Vanuatu and WSa= Western Samoa.
The letter 'x' indicates *A.dispersus* indication for presence and concern.
Information retrieved from Barro *et al*. (1997).

Management. Utilising natural enemies reduces the risk of pesticide usage that results into environmental pollution increase. The importation of parasitoids of genera *Encarsia* or *Eretmocerus* and of various predators have been successfully used in greenhouses for whitefly control (Gerling *et al.*, 2001). The three parasitic species, *Eretmocerus mundus* (Mercet), *Eretmocerus eremicus* Rose and Zolnerowich and *Encarsia formosa* Gahan (*Hymenoptera: Aphelinidae*) have been used against whiteflies in Japan (Sugiyama *et al.*, 2011).

In Fiji, the common predators of *A. dispersus* are *Coccinellids Megalocarla* (= *Archaioneda tricolor*) *fijiensis*, *Serangiella* and the *Neuropteran cbrysop* [Kumar *et al.* (1987) cited in Waterhouse and Norris (1989)]. Some common predators of whiteflies are lacewings, big-eyed bugs, minute pirate bugs and several lady beetles (For example; *Scymnus* or *Chilocorus* species). A major outbreak of Spiralling whiteflies on Papaya was reported in Samoa (Pestnet, 2005). The outbreak of whiteflies usually happens when their natural enemies are disturbed or destroyed by pesticides, dust build-up and other factors. These outbreaks commonly affected guavas, palms, ground orchids, and poinsettias (ornamental). A recent study showed that *A. swirskii* (mite) is increasingly used for the biological control of thrips and whiteflies in many crops (Messelink *et al.*, 2008). Three major predators that have been found to be most effective in attacking Spiralling whiteflies are *Megalocaria fijiensis*, *Serangiella* and the neuropteran *chrysopa* species (Waterhouse and Norris, 1989).

According to Waterhouse and Norris (1989), the establishment of Pacific bridgehead in Hawaii (1978) led to spread of Spiralling whiteflies to many of the Pacific nations. Parasitic wasps *Encarsia* (?) *haitiensis*, *Encarsia* species and three coccinellid predators from Trinidad were used as biological agents to reduce the damaging populations of whitefly in Guam. It was noted in Lanai Island (Hawaii) that *E.* (*?*) *haitiensis* and *Encarsia* species could effectively control the Spiralling whitefly. Adult whiteflies were observed on buses, cars and near parking areas. By late 1979, *A. dispersus* was considered to be an economic pest and initiated a search for natural enemies in the Caribbean. Different species of coccinellid predators and aphelinid parasite were introduced in 1979 and 1980 to reduce the population of *A. dispersus*. In Fiji, *A. dispersus* spread rapidly and became a serious pest since 1986. The introduction of *Encarsia* (?) *haitiensis, N. oculatus* and *N. bieolor* from Guam and Hawaii became well established up to 2 km from their release sites. The three predators found to attack *A.dispersus* prior to 1986 were the coccinellids *Megalocarla fijiensis, Serangiella* sp. and the neuropteran *Chrysopa* sp. Similarly, in American Samoa, *A. dispersus* were found in 1981 on a wide range of plants including ornamentals, citrus and other fruit trees. The introduction of coccinellid predators and the parasite *Encarsia* (?) *haitiensis* in 1984 from Hawaii rapidly reduced the *A. dispersus* population. Table 2 provides detail as where the Spiralling whiteflies were discovered, their host range and biological control in Hawaii, American Samoa, Cook Islands, Fiji, Pohnpei, Guam, Kiribati, Palau, Papua New Guinea, Tonga and Western Samoa.

Physical control of A. dispersus - removal and traps. Removal of leaves may be an environmental friendly approach, but it does not completely remove the pest, it rather lessens the level of whitefly population from the plant. A slight infestation can quickly spread to other plants. The removal of leaves is a good approach to get rid of non-mobile nymphal and pupal stages of whiteflies from highly dense leaves.

In addition, yellow sticky traps are used to trap adults since whiteflies are attracted to yellow (Barbedo, 2014). It is where a trap consisting strips of paper and sticky substances such as petroleum are placed in the greenhouse. The insects are caught as they fly. The drawback of this type of approach is that it only captures specimens that can fly. However it is generally ineffective for the insects that are in their early stages since they are not able to fly (Barbedo, 2014). This method is not a full-proof control method for farmers since it does not eliminate damaging population, but aims to reduce the whitefly population (Nakamura *et al.*, 2007).

Botanicals. Natural pesticides such as plant essential oils would represent an alternative in crop protection (Coats, 1994; Isman, 2000; Koul *et al.*, 2008). Different plants have been used for the control of pests and the research has worked out well (Gonzalez-Coloma *et al.*, 2010). Medicinal plants can be an alternative to a lot of synthetic chemicals for human health and agriculture. However, people in Fiji and the rest of the South Pacific countries are not very cognizant of the presence of the great plant diversity surrounding them. The only study published in relation to botanical effects against *A. dispersus* were carried by Chand *et al.* (2016). Plant extracts such as essential oils from these medicinal plants could possibly be used in agriculture in the form of pest controls. The study focused

Table 2 - Introductions for the biological control of *A.dispersus*

Country	*Aleurodicus dispersus*		
	Discovered place and Year	Plants on which they were found first	Introduction of biological Control
Hawaii	Honululu in September 1978	Tropical almond	Coleoptera. *Delphastus pusillus* (1980) from Trinidad. *Nephaspis oculatus* (1979) from Trinidad. *Nephaspis oculatus* (1979) from Honduras. *N. bicolor*(1979) from Trinidad. Hymenoptera. E. ? haitiensis (1979) from Trinidad. *Encarsia sp.* (1980) from Trinidad.
American Samoa	Tutuila in 1981	Guava, ornamentals, citrus and other fruit trees. Infestations were noted on banana leaves and later in vegetable gardens	Coleoptera. *Delphastus pusillus* (1984) from Hawaii. *Nephaspis oculatus* (1984) from Hawaii. *Nephaspis bicolor* (1984) from Hawaii. Hymenoptera. *E.? haitiensis* (1984) from Hawaii.
Cook Islands	Rarotonga in 1984	Frangipani, guava, hibiscus and mango	Coleoptera. *? Nephaspis bicolor* (1985) from Hawaii. Hymenoptera. *?Encarsia ? haitiensis* (1985) from Hawaii. *Encarsia ? haitiensis* (1988) from Fiji.
Fiji	Suva in April 1986	--	Coleoptera. *Nephaspis oculatus* (1987) from Guam. *Nephaspis oculatus* (1987) from Hawaii. *N. bicolor* (1987) from Hawaii. Hymenoptera. *E. ? haitiensis* (1987) from Guam. *E. ? haitiensis* (1987) from Hawaii.
Pohnpei	--	--	Hymenoptera. *E.? haitiensis* (1986) from Guam.
Guam	Guam in 1981	Coconut, frangipani, guava and mango	Coleoptera. *Nephaspis oculatus* (1981) from Hawaii. Hymenoptera. Encarsia ? haitiensis (1981) from Hawaii
Kiribati	Bikenibeu, Tarawa, in June 1988	Chillies, bell peppers, tomatoes, pawpaw, guava, breadfruit, banana, ornarnentals -including, frangipani and Coleus	A biological control project is to be commenced in the near future
Palau	--	--	Hymenoptera. *E.? haitiensis* (1986) from Guam.
Papua New Guinea	October 1987 in the Port Moresby	Guava, mango leaves and coconut palms	*Coccinellids and spiders were seen preying on them
Tonga	In November, 1988	--	*attacked by Unidentified wasps.
Western Samoa	First recognised in 1985	--	--

on five common medicinal plants randomly selected and screened for the insecticidal properties (fumigant and repellent test). These medicinal plants were Makosoi (*Cananga odorata*), Lemon grass (*Cymbopogon. citratus*), Curry Leaves [*Murraya. koenigii* (L.) Spreng] Tulsi [*Ocimum tenuiflorum* (L.)] and Uci (*Euodia. hortensis forma hortensis*). The results revealed that Tulsi essential oils showed strong fumigant toxicity (100% mortality in 3 hours) while Lemon grass and Curry leaves showed the best repellent effect with LC_{50} value of 0.004 and 0.113, respectively (Chand *et al.*, 2016).

Chemical control. The use insecticides are widespread among farmers. For instance the paper by Kajita *et al.* (1991) provides a description of several insecticides against *A. dispersus* on soya beans in Indonesia. However, because the whitefly has wide host-plant ranges in addition to the fact that insecticides also have impact on natural enemies, chemical control is usually considered impractical and uneconomic in the long-term (Kajita *et al.*, 1991; Lambkin, 1998). Carmichael *et al.* (2008) also discourage the use of chemical control for managing Spiralling whiteflies, suggesting that soaps and detergents can provide effective control in small scale planting. In the South Pacific, there are no recorded publications dealing with chemical control measures of *A. dispersus* yet (Waterhouse and Norris, 1987).

According to Reddy (2015), the common chemicals used for controlling whiteflies are *dimethoate 30 EC* at 0.05% and insecticidal soap at 2.5%, which deterred the adults. Likewise, the following chemicals imidacloprid, buprofezin and pyridaben are also used to manage whiteflies (Bi *et al.*, 2002). Spiromesifen, a novel insecticide inhibited egg hatching in green house by 80% to 100% at the concentrations of 3.1, 3.0, and 10.0 $\mu g\ mL^{-1}$. The insecticide also showed mortality of 100% for the first, second, and third instar nymphs of whiteflies (Toscano and Bi, 2007).

Chemical approach mostly kills those that come in contact with the insecticides (chemicals). The use of the chemical approach showed efficiency towards controlling pests in small and in large scale farms. For instance, farmers in Colombia intensify the use of insecticides, as the whiteflies reduced the crop yield by 79% (Carabalí *et al.*, 2010). Although, plant productions may have increased due to pesticidal applications at the same time these chemicals may have raised detrimental concerns for so many (Aktar *et al.*, 2009). Chemical pollution is a major concern to the environment and to human health due to the bioaccumulation of chemicals through food chains, resulting in severe physiological disorders and diseases (Oliva *et al.*, 2001; Baldi *et al.*, 2003; Briggs, 2003; Saiyed *et al.*, 2003; Lemaire *et al.*, 2004). The extensive use of synthetic chemicals has led to pests in developing resistance to chemicals and at the same time resulting into the accumulation of harmful chemical pollutants in the environment. These pollutants gradually affect the quality of air and water, on which many organisms rely on.

5. Conclusions and future perspective

Whiteflies are considered serious pests to vegetation and ornamental plants in many countries and as such, Spiralling whiteflies are fast becoming a concern for many farmers in the Pacific and other parts of the world. In the South Pacific the pest has been reported in Majuro (1986) (Marshall Is), Cook Islands (1984), Fiji (1985), Nauru (1987), Papua New Guinea (1987), Kiribati (June 1988), Tokelau (late 1988) and Tonga (November 1988) (Waterhouse and Norris, 1987). These whiteflies feed exclusively on leaves, which eventually damage the plant leading to diseases or plant death. Whiteflies are very difficult to manage as a result of multi host plants that support their lifespan. The most common management practices used for the control of whiteflies are biological control using the parasitic wasps, predators and entomopathogenic fungi, physical method using removal and traps, botanicals such as plant extracts and essential oils, and chemical control. At present there is no available literature in the South Pacific that provides data on chemical and physical practices. The only data available were on biological control methods and the use of botanicals (essential oils) for the management of *A. dispersus* (Waterhouse and Norris, 1987; Chand *et al.*, 2016). The salient findings gathered from this review indicate a general lack of information and research on the current status and the degree of damages that the Spiralling whitefly has inflicted on agricultural and ornamental crops in the South Pacific.

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