

Parasitisation of the spiralling whitefly, *Aleurodicus dispersus* Russell (Homoptera: Aleyrodidae), by *Encarsia* spp. (Hymenoptera: Aphelinidae) in relation to hostplant and weather factors

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Abstract

In Nigeria, the spiralling whitefly (SWF), *Aleurodicus dispersus*, is a highly polyphagous and serious pest of horticultural crops. Although its parasitoid, *Encarsia* sp., has been accidentally introduced, information on its suitability in the ecosystem is still scanty. The study therefore investigated factors influencing whitefly parasitisation by *Encarsia* sp, from 2014 to 2019 on *Citrus sinensis* (sweet orange), *Acalypha wilkensiana* (red acalypha), *Ficus polita* (fig) and *Psidium guajava* (guava) at two sites in Ibadan, Nigeria. SWF abundance and mummification, and weather factors were monitored monthly and correlated. Total rainfall and mean temperature were significantly associated ($P < 0.05$) with both SWF density and parasitisation, while *Encarsia* sp., the only natural enemy found during the study, improved the regulation of SWF on all the hostplants at both sites. Number of parasitoids was highly correlated and synchronized ($P < 0.05$) with that of SWF throughout the sampling period although the spatial patterns of parasitism distribution in relation to SWF population density were not totally directly density dependent. Local extinction of SWF was observed on *Citrus*, *Acalypha* and *Ficus* spp., whereas whitefly regulation with reduced and stabilized numbers and stable percentage parasitism was evident on *Psidium*. While there was no significant difference ($P > 0.05$) between parasitism indices either within or between sites on *Psidium*, the cumulative numbers of SWF were significantly higher ($P < 0.05$) than other hostplants. The continued presence of the regulated SWF number on *Psidium* and its extinction on *Citrus*, *Acalypha* and *Ficus* suggested a combination of hostplant quality and *Encarsia* sp. as major factors in SWF regulation.

Introduction

The spiralling whitefly, *A. dispersus*, is a highly polyphagous and serious pest of guava, pawpaw, banana / plantain, cassava, many vegetables and ornamentals (Ajuonu *et al.*, 2011). The pest, which is a native of the Caribbean region and Central America (Russell, 1965) was first noticed as a pest in Hawaii in 1978 (Kumashiro *et al.* 1983) and has since spread across the pacific and southeast Asia (Srinivasa, 2000). It was first reported from Africa in the early 1992 in Ibadan and Lagos, Nigeria (Akinlosotu *et al.* 1993) and thereafter, in Benin, Togo, Ghana and Congo (Neuenschwander 1994; Ajuonu *et al.* 2011) where it occurred in large numbers on at least 32 different plant families. In Nigeria, Pitan *et al.* (2008) recorded the pest on at least 66 species of beneficial plants in 32 different plant families including fruit crops, ornamentals, tuber crops and shade trees. The most important hosts were guava (*Psidium guajava*), almond tree (*Terminalia catappa*), fig *Ficus* spp.), acalypha (*Acalypha* spp.), oranges (*Citrus* spp.) and cassava *Manihot esculenta*).

A. dispersus sucks sap from leaves and secretes honeydew which encourages the growth of sooty mould on the foliage. The mould inhibits photosynthesis and causes leaf drop leading to a marked reduction in fruit production (Pitan, 2003). Infestations pose a serious threat to subsistent farmers in areas where fruit crops and vegetables are often the most freely available food providing energy and vitamins in the diet and where ornamentals are planted for shade and aesthetic beauty (Zakkum *et al.* 2024). Some of the pest control measures adopted by growers in Nigeria, which only gave short-lived

control, include pruning and outright felling and burning of the infested plants; and application of insecticides (Boopathi *et al.* 2017). Although, Sampiano *et al.* (2024) suggested certain natural oils for control, Akinlosotu *et al.* (1993) proposed the use of natural enemies as a reliable and ecologically sound control option for mitigating the spiralling whitefly menace in Nigeria due to its exotic and polyphagous nature.

Due to the importance of the spiralling whitefly to horticulture in Nigeria, a nation-wide biological control of the spiralling whitefly project was initiated in 1993 with the initial task of determining the status of the *A. dispersus* infestation in Nigeria. Remarkably, in all areas surveyed in Nigeria, *Encasia dispersa* Dozier (Hymenoptera: Encyrtidae), a natural enemy of *A. dispersus* was found together with the whitefly (Akinlosotu *et al.* 1993; Pitan *et al.* 2008). *Encasia dispersa* is a primary parasitoid of the spiralling whitefly. It has been used effectively either singly or in combination with other natural enemies in previous attempts at the biological control of *A. dispersus* in Hawaii, Pacific countries such as Palau and Pohnpei and in the Maldives with varying degrees of successes (Neuenschwander, 1994; Chand *et al.* 2018)). Since there was no record of any formal release of the parasitoid anywhere in Nigeria, the wasp must have arrived by accident, presumably together with *A. dispersus*. It is therefore, necessary to determine the suitability of the introduced natural enemy in order to determine whether further importations of other natural enemies would be necessary. In practice, evaluation of the efficacy of biological control agents is very important in any biological control programme and has been recognized as the key to the development of biological control as a science (Chand *et al.* 2018). Long-term population dynamics studies are no doubt the backbone of such evaluations and will clearly provide the most important demonstration of impact. Therefore, this study was designed to determine the temporal patterns of the distribution of the spiralling whitefly on 4 different host plants and to highlight major factors in whitefly population fluctuations with emphasis on the evaluation of *Encasia* sp. as an efficient biological control agent.

Materials and methods

Study Area

The study was carried out between January, 2014 and December, 2019 in Ibadan, southwest of Nigeria (guinea savannah zone) (7°30'N, 3°54'E, 210 m above sea level) at two of the sites where growers reported heavy infestation of *A. dispersus* in 2010. Generally, in southern Nigeria, the rainfall pattern is bimodal, with a long rainy season lasting from March to July followed by a dry spell. The short rainy season lasts from September until November. Until February-March the weather is dry, with frequent periods of 'harmattan', a dry, dusty wind originating in the Sahara Desert.

The first site was in Bashorun area in the north eastern part of Ibadan and contained the following hosts: 6 stands of *Citrus sinensis*, 2 of *Ficus polita*, 4 of *Psidium guajava*, 28 of *Acalypha wickeysiana*, 2 of *Mangifera indica* (mango), 11 of *Carica papaya* (pawpaw) and 18 of *Musa paradisiaca* (plantain). At the second site which was at Jericho Reservation Area, south of Ibadan, had 4 stands of *Citrus sinensis*, 2 of

Ficus polita, 2 of *Psidium guajava* and 101 of *Acalypha wilkensisiana*. A preliminary visual examination was made of all the plants in the study areas to determine the severity of infestation. One severely infested plant was selected from only four hosts for sampling in this study - *Citrus sinensis*, *Ficus polita*, *Psidium guajava* and *Acalypha wilkensisiana* because they were common to the two sites, making a total of 4 plants per site (i.e. 8 plants in all).

Monitoring of the spiralling whitefly and its parasitoid

For monitoring of *A. dispersus* population densities on the four host plants, the sampling procedure was as follows: 20 leaves per host tree were randomly selected for examination once a month from the bottom, middle and top parts of the host plants. Counts of adults, nymphs and parasitised *A. dispersus* (mummies) were made *in situ* and were recorded separately. After removing live insects, others were kept in the laboratory for 3–4 weeks until emergence of primary parasitoids was completed. In order to allow comparisons to be made between the different host plants with leaf sizes greatly varied, the total number of the spiralling whitefly (adults, nymphs and mummies) was calculated on a leaf surface area basis. To do this, leaf surface areas of 5 randomly selected leaves out of the 20 leaves sampled from each host plant were measured and the mean ($\bar{x}$) was multiplied by the number of leaves sampled (s) to give the total leaf area sampled ($s\bar{x}$). The number of *A. dispersus* and *Encasia* spp. per square centimeter (w/cm^2) was then determined by dividing the total number of whiteflies found per sample per host plant (t) by the calculated leaf area ($w/cm^2 = t/s\bar{x}$) (Tingle and Copland, 1987). Differences in the population densities of *A. dispersus* and *Encasia* per square centimeter of the leaf areas on different host plants were detected using student's t-tests ($P < 0.05$) after such data were arcsine-transformed.

Temperature and rainfall data collection

Average monthly temperature and rainfall data collected to determine a possible influence of rainfall and temperature on *A. dispersus* densities. The data covered the rainfall of the month preceding each sampling time. Correlation and regression analyses (Draper and Smith 1981) were carried out to determine the relative importance of different ecological factors examined.

Density dependence of *Encasia* sp.

Parasitism index was computed and was transformed into the arcsine of its square root and plotted against $\log(x + 1)$ – transformed whitefly densities. The significance of the slopes was judged with a t-test at $P \leq 0.05$ (Boavida and Neuenschwander 2010; Ajuonu *et al.* 2011).

Results

Rainfall and temperature pattern, population fluctuation of the spiralling whitefly and its parasitoid, *Encasia* sp., on each of the 4 host plants at the 2 sites are presented in Figs. 1–3. Between 2014 and 2019, there was a sharp, consistent and irredeemable decline in the population densities of the whitefly

to zero from 2016 on *Citrus*, *Acalypha* and *Ficus* spp. at the two experimental sites. The data from the first sample and those taken between January and May, 2014 at the two sites showed significant differences in the densities of *A. dispersus* on the different host plants ($P < 0.05$). But marked reduction in the numbers of *A. dispersus* was noticed from the 6th month (June, 2014) (Figs. 2 & 3); the reduction became significant ($P < 0.05$) on *Citrus*, *Acalypha* and *Fig* at the end of the second year (2015); and at the end of the third year for *Psidium*. Largely, on the four hosts, following the detection of *Encasia* sp. peaks of *A. dispersus* infestations, estimated from the numbers of adult whiteflies became lower each year. In 2015, peaks reached only about 20% of those of 2014. The total number of parasitized pupae increased from one year to the next (Figs. 2 and 3), indicating that parasitism rates generally increased from 1993 to 1996. On *Psidium* at the two sites, whitefly numbers decreased and remained relatively constant at a low level while percent parasitism was stable. Although initial whitefly densities varied significantly between trees, fluctuation trends were similar on each of the host plants. At each site, there was a significantly higher number of *A. dispersus* than on other host plants in which in themselves were not significantly different ($P < 0.05$). There was no difference between the densities of *A. dispersus* on *Psidium* at the two sites but significant differences occurred between the population densities of *A. dispersus* on *Psidium* and other host plants both within and between sites (Table 1).

On the other hand, percent parasitism did not differ significantly on plants within or between the sites even though it varied significantly at the first sampling in January, 2014 and was observed to be highest on *Acalypha* (Fig. 4). The abundance of the parasitoid followed the same pattern as that of the host on the 4 host plants, which illustrates the ability of the parasitoid population to track down the spiralling whitefly population densities. The parasitoid population varied greatly with plant species but generally peaks of percentage parasitism occurred at the same periods of the year on the different plant species (Figs. 2 and 3). This suggests that plant species have an important role to play on the level of parasitism observed. There was no significant correlation between percent parasitism and mean temperature during the sampling period on any of the host plants studied (Table 2). The contributions of various biotic and abiotic factors to the size of whitefly populations on the four hostplants were quantified in a multiple regression analysis (Tables 3). On the basis of infested trees, three independent factors influenced *A. dispersus* populations. Parasitism played a very important role in the occurrence of *A. dispersus*, with the highest values found on *Citrus*, *Acalypha* and *Ficus* spp. relative to *Psidium* at the two experimental sites. The second most important influence was temperature while rainfall was clearly not a major factor. However, the relatedness of whitefly parasitism and temperature as well as rainfall was low though significant. Slope (b) which represents the rate of change, and in this case rate of population collapse was significant and higher with parasitism than those of other factors at the two sites. In addition, parasitism was found to be density-dependent on *Acalypha*, *Citrus* and *Ficus* judged by the significance of the regression coefficients but on *Psidium*, it was a density-independent relationship (Table 4). The similarity in the trends of the results from the two sites justified the pooling of data to determine the functional relationship between *A. dispersus* and its parasitoid which was found to be polynomial in all cases with a 6th degree on *Psidium*, 5th degree on *Ficus*, 3rd on both *Citrus* and *Acalypha* spp. (Fig. 4).

Discussion

Results showed that the degree of pest regulation achieved was not uniform but depended on host plants; there was also a general marked decline in the population of the whitefly from 2014 to 2019 on all the host plants at the two sites. The positive correlation between *A. dispersus* population and rainfall on the one hand and temperature on the other suggests that both factors influenced the population of the spiralling whitefly. The direct influence of the rain could be the washing-off of whiteflies from host leaves while the indirect is mediated through the physiological condition of the host plants could be responsible (Mani and Krishnamoorthy 2002; Mani *et al.* 2004). But because of the low correlation between whitefly population and each of temperature and rainfall on the four host plants, the sudden decline of *A. dispersus* population following the peaks and the reduction in *A. dispersus* population density which also occurred in both the raining and dry season, the impact of rainfall and temperature on *A. dispersus*, though important, was considered minor.

Although temperature may not be the factor inducing whitefly outbreaks (on *Psidium*) as stated earlier, the significant correlation between temperature and percent parasitism on the host plants at the two sites indicated that temperature influenced parasitism and is important probably in determining parasitoid efficiency. Similar reports on the influence of temperature have been reported on the searching, oviposition and developmental rates of *Leptomastix abnormis* Girault and *Leptomastix dactylopii* Howard and consequently on the control of *Planococcus citri* Risso by the parasitoids (Tingle and Copeland 1987). These features of parasitoids that are affected by temperature are those that contribute to success of the natural enemy in terms of number of hosts parasitized at a given time.

The decline in the population of the whitefly observed on the 4 host plants might be a result of the temporal synchrony of the numbers of *Encasia* sp. with that of the hosts, and which resulted in the highly significant correlation that existed between the two populations on each of the host plants. Rate of decline was very high on the indicating steepest slope was obtained with parasitism on the four hosts, though higher on *Acalypha*, *Citrus* and *Ficus* than *Psidium*. Only a natural enemy, in this case *Encasia* sp. appeared to be capable of causing that type of variation in the host's population. Though positive density dependence has rarely been found in natural host–parasitoid interactions despite their apparent stability (Mani *et al.* 2004), *Encasia* sp. appeared to show this type of dependence on the population of *A. dispersus* in the first two years of sampling on the four host plants. Some of the attributes of the parasitoid that could enable such a response include high fecundity and shorter generation time compared with that of its host (Tanga *et al.* 2013).

The extinction of *A. dispersus* on *Citrus*, *Ficus* and *Acalypha* at different times during the study agrees with modern reasoning that biological control is compatible with local pest extinctions (Tanga *et al.* 2013). Similarly, the marked reduction in the population density of the whiteflies on *Psidium* and lack of pest outbreaks subsequently indicated that a stable relationship had been established between the parasitoid and its host. It also implies that the *Encasia* sp. is adequately regulating the number of *A. dispersus* though it appears it may not be able to singly cause the extinction of *A. dispersus* on *Psidium*.

Such differences in pest numbers on different host plants have also been reported for some aphids (Wellings and Dixon 1987) and the level of control achieved by the aphelinid parasitoid, *Encasia formosa* Gahan on *Trialeurodes vaporarium*. This was attributed to a combination of the effect of the host plant on pest fecundity, lifespan and developmental rate and on the searching efficiency by the parasitoid (Ajuonu *et al.* 2011). Several plant features such as leaf surface topography and toxic secondary substances have also been reported to affect parasitoids' efficacy (Campbell and Duffey 1979). This suggests that plant susceptibility to insects may result from the detrimental effects of plant antibiotics on the biological control agents of insect pests in question.

Though there was no enough evidence from the present study to suggest that the fecundity and lifespan of *A. dispersus* were more stimulated on *Psidium* than other host plants, significantly higher population of *A. dispersus* observed on *Psidium* is an agreement with earlier report that total developmental time for *A. dispersus* is shorter on *Psidium* than on *Citrus*, *Acalypha* and *Ficus* in that order (Pitan and Odebiyi 2002; Han *et al.* 2009). The shorter developmental time on *Psidium* suggests that more whiteflies would be found on the plant, while an impressive control (and in fact extinction) of the whitefly would be more likely on *Citrus*, *Acalypha* and *Ficus* where replacement of parasitized *A. dispersus* is much slower due to more prolonged developmental time compared to *Psidium*. The 6th degree polynomial relationship recorded on *Acalypha* also suggest that more factors regulate the population density of *A. dispersus* on the plant compared to the other hosts trialed and therefore, will be take more time to achieve whitefly extinction than on *Citrus*, *Acalypha* and *Ficus* spp. Both sets of data from the two orchards demonstrate a decline in *A. dispersus* populations with increasing time of parasitoid presence. Since other factors remained mostly unchanged, the decline is attributed to this exotic parasitoid.

It is concluded that differences in pest regulation observed on *Psidium*, *Citrus*, *Acalypha* and *Ficus* are entirely due to an effect on the parasitoid. The significant correlation between parasitism and temperature and not whitefly population density and temperature indicate that the effect of temperature is likely to on the parasitoid rather than the whitefly. Similarly, the significance of the relationship between rainfall and whitefly population density and not parasitism means the effect of rainfall is on the whiteflies. However, the fact that *Psidium* still harbours whitefly numbers suggest that rainfall and temperature are minor factors, and hostplant and parasitism major factors. Therefore, although rainfall and temperature are important factors too, they are considered minor in this study, while *Encasia* sp. and host plant qualities were major factors affecting the population of *A. dispersus* and are important in its regulation.

Declarations

The authors declare that this manuscript has not been considered elsewhere for publication.

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Author's contribution statements: Dr. FILANI, OYINDAMOLA CAROLINE carried out the research work and wrote up the paper.

Prof. PITAN, OLUFEMI RICHARD conceived the experiment and review the paper write-up.

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Data availability Not applicable in the study.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest regarding the publication of this paper.

Ethics approval This study does not involve human participants and so ethics approval is not applicable.

Consent No consent was required for the study.

Code availability Not applicable in the study.

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Tables

Tables 1 to 4 are available in the Supplementary Files section.

Figures

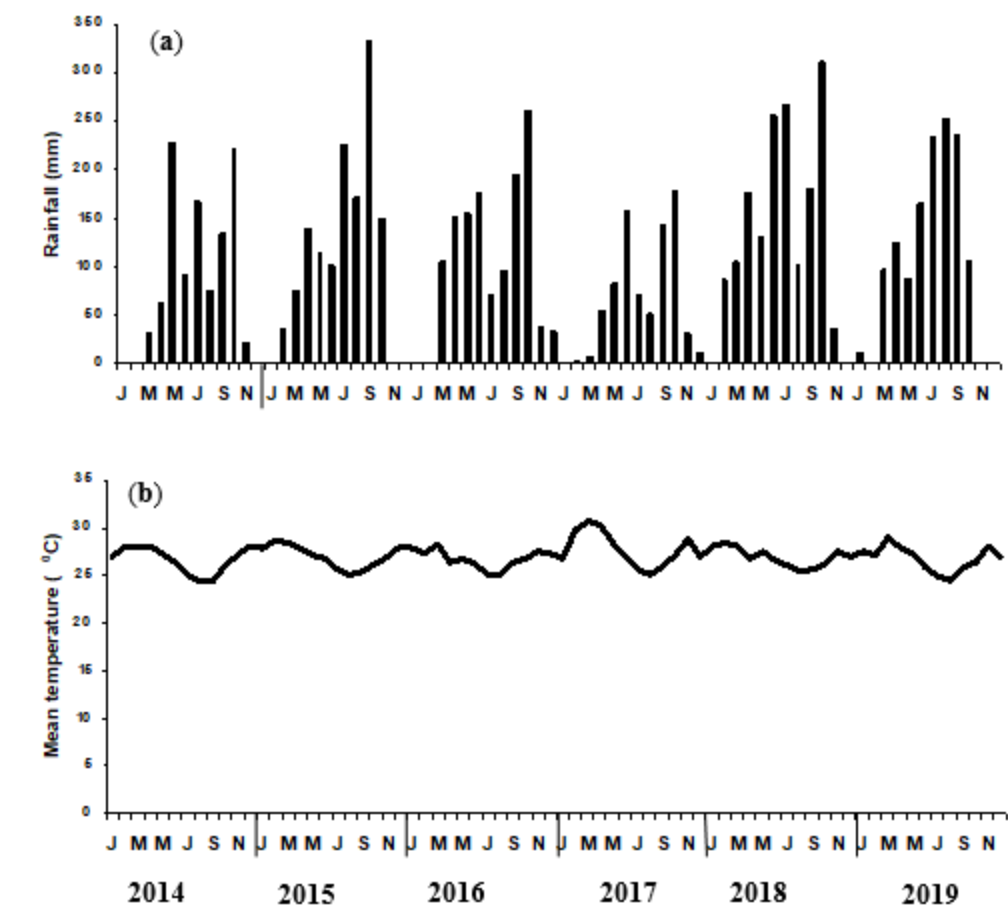


Figure 1

Daily rainfall (a) and average monthly temperature (b) between 2014 and 2019 in Ibadan, a typical guinea savanna zone.

Source: The National Horticultural Research Institute, Ibadan, Nigeria.

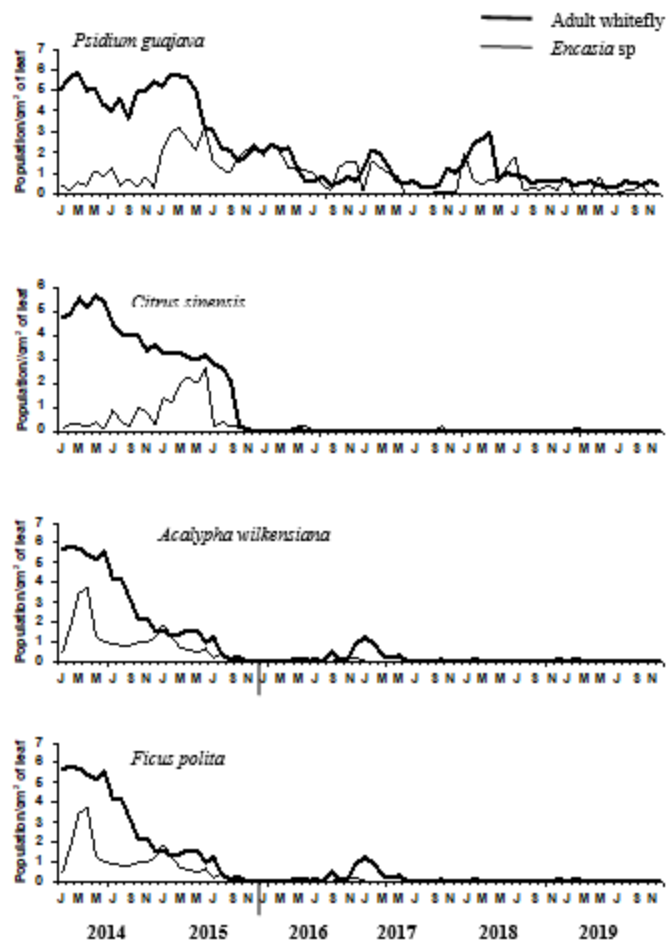


Figure 2

Population fluctuations of *Aleurodicus dispersus* and its parasitoid, *Encasia* sp. between January 2014 and December 2019 on different host plants in the first site.

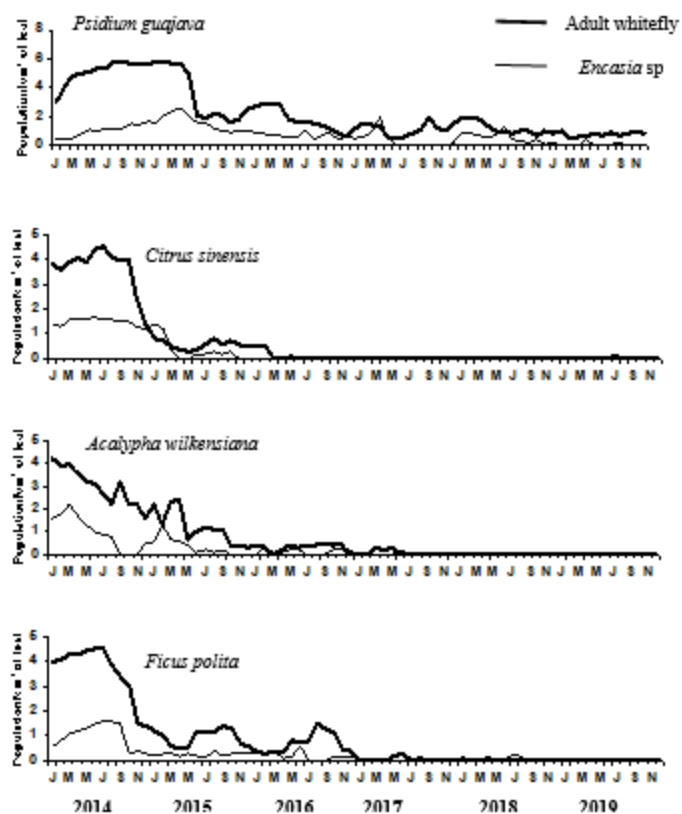


Figure 3

Population fluctuations of *Aleurodicus dispersus* and its parasitoid, *Encasia* sp. between January 2014 and December 2019 on different host plants in the second site.

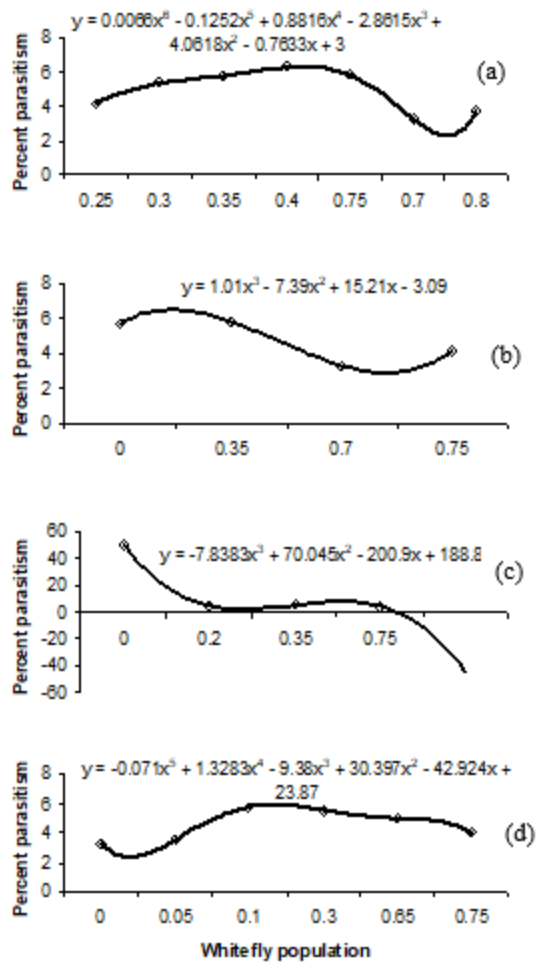


Figure 4

The functional relationship between parasitoid activity (parasitism index) and whitefly population density on (a) *Psidium*, (b) *Citrus*, (c) *Acalypha*, (d) *Ficus* spp.

Supplementary Files

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