

# Whitefly, Host Plant and Parasitoid: A Review on Their Interactions

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## ABSTRACT

The whitefly, *Bemisia tabaci* (Gennadius) is an enormously polyphagous insect pest showing the intercrop movement, high reproduction, resistances to insecticides, under-leaf habitat, and virus transmission. In the past decades, numerous studies revealed the interactions of whitefly, host plant, and their natural enemies. The oviposition, development, survivorship, and behavior of *B. tabaci* are mostly mediated by host plants. Numerous parasitoid species are essential components controlling whiteflies biologically; they parasitize whitefly nymphs and kill them through active feeding. Studies showed that appropriate conservation and augmentation techniques of parasitoids can make them more dynamic on the crops in protected environment and even in exposed cropping field. Moreover, the performance of parasitoid is influenced by several factors including number and release rate of parasitoid, intra- and inter-specific competition, stage, size and density of whitefly nymph as well as environmental factors and host plants. In this review, we summarized the progress and findings of how *B. tabaci* adapt on various plant species, interactions of host plant and the whitefly, *B. tabaci*, interactions between parasitoids and plant species, interactions among parasitoid species, interactions among host plant, *B. tabaci* and parasitoid in the last decade. We also discussed the possibility of using parasitoids for suppression of whitefly populations.

**Keywords:** biological control, whitefly, host plants, parasitoids, interactions

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## INTRODUCTION

The whitefly, *Bemisia tabaci* (Gennadius) is one of the most important insect pests of most vegetables, some ornaments and agronomic crops especially in the sub-tropical and tropical regions around the world (Liu, 2007; Wan et al., 2009; Zhang et al., 2007). The whitefly has association with almost 600 different species of plants (Martin et al., 2000; Naranjo and Ellsworth, 2009; Secker et al., 1998) which comprise large number of cultivated and non-cultivated, annuals and perennials (Bedford et al., 1992; Brown et al., 1995; Butler and Henneberry, 1986). Systematic studies of the *B. tabaci* reveal convincing evidence that *B. tabaci* is a complex species including at least 35 cryptic species with extensive genetic diversity (Ahmed et al., 2013; Bing et al., 2013; De Barro et al., 2011; Dinsdale et al., 2010; Hu et al., 2011; Liu et al., 2012; Wang et al., 2011; Xu et al., 2011) which show diverse behavior concerning to host plant preference, oviposition, ecological adaptation as well as virus dissemination (De Barro et al., 2005; Perring, 2001). Furthermore, it can be simply adapt to the new host plants in the new area because of its distinctive biological and behavioral characteristics.

With the introduction of synthetic chemical insecticides in the 1950s, pest control has been mostly relied on that; however, it soon became noticeable that there were problems associated with the use of insecticides. At present, the management of insect and mite pests in agricultural systems still relies primarily on the use of chemicals, and consequently, many insect pests became resistant to chemical insecticides, including the whitefly *B. tabaci* (Brun-Barale et al., 2010; Byrne et al., 2010; Mallet, 1989; Schuster et al., 2010). In addition, the extensive use of insecticides adversely affected non-target organisms and caused secondary pest resurgence with environmental and health concerns.

Establish a long lasting integrated pest management system using efficient natural enemies is an encouraging decision. Parasitoids have drawn significant attention because of their importance in biological control of insect pests through parasitism and host feeding (Chan and Godfray, 1993). The host feeding mostly involves in consumption of host fluids, secreted during oviposition which has reported in at least 140 species belonging 17 families of Hymenoptera (Jervis and Kidd, 1986; Zang and Liu, 2010; Zang et al., 2011a,b). About 10,000 wasp species feed their host (Kidd and Jervis, 1989) that supplies nutrients to the parasitoids assisting egg development (Heimpel and Collier, 1996; Jervis and Kidd, 1986) and consequently increases parasitoid's egg production (Burger et al., 2005; Giron et al., 2004; Rivero and Casas, 1999; Ueno, 1999). In view of that consideration, host feeding activities believed an encouraging attribute of parasitoids as selecting a candidate for biological control agent (Jervis and Kidd, 1986; Zang and Liu, 2010; Zang et al., 2011a). Whiteflies show multivoltine characters, they have no diapauses or dormant stages. Therefore, whiteflies are constant through the frequent utilization of numerous plant host resources over the annual cycle (Naranjo et al., 2009). Movement from one plant host species to another is consequently an essential element of the whitefly ecology which facilitates finding host plants and colonization in a frequently variable ecosystem. In this paper, we reviewed the recent evolution and findings of adaptation of *B. tabaci* on various plants and ecosystem, and their interactions with parasitoids in different aspects in the last decade. We hope that this review will provide comprehensive information about *B. tabaci*, host plant, and parasitic natural enemies and to stimulate more research in these needed areas.

## ADAPTATION OF BEMISIA TABACI TO VARIOUS HOST PLANTS AND CROP SYSTEM

While and wherever a female insect lays eggs or deposits larvae have a determining influence on her fitness as well as adaptation. Feeding and oviposition are crucial for host selection in herbivores that enhance them to adapt to a new host. It was thought that both the plant nutrients and secondary volatile chemicals might be the most critical for insects to establish them on a particular host. However, whiteflies have ability to adapt to new host plants and zones for the reasons of its sole biochemical and biological characteristics. Carabali et al. (2005) believed that *B. tabaci* acclimate potentially in the Neotropics that consider a great threat for cassava cultivation. To confirm their assumption, Carabali et al. (2005) carried out an experiment whether *B. tabaci* B biotype can establish on the cassava plant (*Manihot esculenta* L.). They found that *B. tabaci* was becoming establish on *M. esculenta*, sequentially started from *Phaseolus vulgaris* L. followed by *Euphorbia pulcherrima* Willd. and *Jatropha gossypifolia* L. In that sequential adaptation, the highest survival rate, and the lowest developmental duration were needed for those whiteflies coming from *J. gossypifolia* as closest phylogenetic host plant. Conversely, Hu et al. (2011) explained that poinsettia derived Q biotype *B. tabaci* is unable to establish rapidly on field crops though it might have some potentiality to adapt.

Population dynamics of *B. tabaci* are regulated primarily by predation (Naranjo and Ellsworth, 2005) as well as by abiotic factors (mostly by temperature) in the field (Naranjo et al., 2003). To concentrate on the population dynamics, Liu (2000) observed few *B. tabaci* populations on collards in winter and did not show any economic significance damage at relatively low temperature as compared with high level of infestation found in the fall and spring. Lin et al. (2007) investigated the overwintering of *B. tabaci* with its population dynamics in northern China, a cold region that how they survive a winter. To address that research, they conducted a cold hardiness test and found that in northern China it is impossible to survive for natural *B. tabaci* populations under natural environment during winter season. Furthermore, they observed that population density of *B. tabaci* was lower at winter and gradually became higher during February-March until they established in the field in the month of April. On the other hand, high temperature is also a reasonable cause for low population densities of ectothermic organisms. Survival of *B. tabaci* adults and hatching of F<sub>1</sub> nymphs were critically affected when whiteflies were exposed to 41°C or higher (Cui et al., 2008), although this study revealed that *B. tabaci* have capability to tolerate at higher temperature than that of *Trialeurodes vaporariorum* (Westwood).

## INTERACTIONS BETWEEN BEMISIA TABACI AND HOST PLANTS

*B. tabaci* infests at least 600 different plant species, though however, it showed preference to Asteraceae, Compositae, Cruciferae, Cucurbitaceae, Euphorbiaceae, Fabaceae, Labiatae, Leguminosae, Malvaceae and Solanaceae families' plants (Bayhan et al., 2006; Elsey and Farnham, 1994; Johnson et al., 1982; Mound and Halsey, 1978), with a distinct affinity to cabbage, cotton, cucumber, eggplant, gerbera, gherkin, melon, poinsettia, squash, sweet potato, and tomato (van Lenteren and Noldus, 1990; Shah and Liu, 2013; Xu et al., 2011; Ying et al., 2003). *B. tabaci* exhibited oviposition choice among different host plants as well as leaf surfaces within a host (Gruenhagen and Perring, 2001a; Liu and Stansly, 1995).

Semiochemicals released by host plants known as kairomones, play a significant role in mediating host choice on the majority of the herbivorous insects (Xiao and Fadamiro, 2009). Lee et al. (2011) described that whitefly adult significantly preferred cucumber to poinsettia, when whiteflies were given to choose between those two host plants.

Nevertheless, if the whiteflies had first established on poinsettia, adults were not attracted successfully on cucumber from poinsettia plants. Even adequate number of adults was not attracted on eggplant, though adults showed preference to eggplant in the primary assay and where offered a choice between eggplant and poinsettia (Lee et al., 2009). This phenomenon reflects the behavioral attributes of adult whiteflies. Similar result was stated by Bird and Krüger (2006) where female *B. tabaci* adult stayed on the same host, and very few movements among host plants were recorded during their observation. Omondi et al. (2005) examined the host preference between two biotypes of *B. tabaci* namely cassava and okra biotype, where cassava biotype significantly chose cassava for oviposition and habitation rather than okra, *Abelmoschus esculentus* L. In contrast, okra populations have had preference on okra and also laid eggs on eggplant, *Solanum melongena* L., tomato, *Solanum lycopersicum* L., garden eggplant, *S. integrifolium* Poir and that on cowpea, *Vigna unguiculata* L., but not on cassava plant. The offspring of okra population developed suitably in almost all host species except for that on cassava and slightly subsisted on pepper, *Capsicum annum* L and cabbage, *Brassica oleracea* L. Shah and Liu (2013) established whitefly populations on eggplant, tomato and cucumber where they found that host preferences were influenced by both whitefly populations and host plants however host plants played stronger role.

The whitefly, *B. tabaci* perform differently on different host species, even though sometimes differs when feeding on dissimilar varieties within a same plant species. Among several varieties or lines of melon (*Cucumis melo* L.), Liu (2003) observed in choice test that fewer *B. tabaci* adults along with eggs were observed on "Hymark" than that on "TAM Sun", "TAM Sun × gl" and "Primo". On the other hand, more eggs were found on "Hymark" and "Primo" than those on "TAM Sun" and "TAM Sun × gl" in no-choice test, but whitefly immature mortality was considerably higher on "Hymark". "Primo" had the utmost numbers of adults and pupae, and also immature developed significantly faster on it than on other varieties. Baldin and Beneduzzi (2010) investigated the host preference of *B. tabaci* biotype B among squash (*Cucurbita pepo* L.) varieties/ lines where the least number of adults was attracted on "Bianca" in choice test. In choice tests, the adult did not prefer to oviposit on the varieties "Novita Plus", "Bianca" and "Sandy" whereas similar results were found for "Bianca", "Novita", "Caserta Cac" and "Sandy" in no-choice test. However, "Sandy" expressed the highest mortality against whitefly nymphs.

Whitefly feeding can induce a defensive response on host plants to the other competing herbivores. Several factors are responsible for the quantity and quality of defensive induction including host plant species and varieties, their growing environments, duration of whitefly feeding on host plants, whitefly population density, etc. Mayer et al. (2002) observed behavioral differences between two herbivores, *Trichoplusia ni* (Hübner) and *Liriomyza trifolii* (Burgess). When these herbivores exposed on plants that were previously infested by *B. tabaci* have shown inferior feeding and oviposition, reduced development and survival. Whereas, a little or no affect on whitefly's feeding and oviposition behaviors when the whitefly was introduced to the plants previously exposed to the leaf miners.

## INTERACTIONS BETWEEN BEMISIA TABACI AND PARASITOIDS

Parasitoids are primarily important agents to manage whiteflies biologically; they parasitize whitefly nymphs to produce their new generations and also feed the whitefly nymphs to improve their fitness. *Encarsia* and *Eretmocerus* are the fundamental genera among the widespread fauna of the *B. tabaci* parasitoids. Gerling et al. (2001) reported 34 *Encarsia* spp., 12 *Eretmocerus* spp., two *Amitus* spp., and one from each *Metaphycus* spp. and *Signiphora* spp.

of *B. tabaci* parasitoids. Besides the Gerling et al. (2001) list, Arnó et al. (2010) further reported 15 *Encarsia* spp. and 10 *Eretmocerus* spp. Childs et al. (2011) also reported eight species of both *Encarsia* and *Eretmocerus* genera from Western Sydney, among them one species was not included either in the list of Gerling et al. (2001) or in that of Arnó et al. (2010). Li et al. (2011) found 41 *Encarsia* spp., 12 *Eretmocerus* spp., two *Amitus* spp. and one *Ablerus* sp. in their survey in south, southeast, north, northwest, and central China.

The majority researches have revealed that premature hosts are usually preferred by parasitoids for feeding, whereas some researches revealed that the mature nymphs are preferred, though host size did not affect on the host feeding (Antolin, 1989; Heimpel and Rosenheim, 1995; Mansaray and Sundufu, 2010; Videllet et al., 1997). It has been examined that *Er. melanoscutus* Zolnerowich and Rose and *En. pergandiella* Howard females parasitized the most on the third instar nymphs and the lowest on the first instar nymphs of *B. tabaci* (Greenberg et al., 2008; Jones and Greenberg, 1999; Liu, 2007) whereas *Er. mundus* Mercet was most successfully parasitized on younger host instars (Ghahari et al., 2005; Greenberg et al., 2008). Zang and Liu (2008) showed that the host feeding capacities were significantly different among *En. formosa* Gahan, *En. sophia* (Girault & Dodd) and *Er. melanoscutus* when offered them either on single instar or diverse instars where *En. sophia* showed better performance for feeding host than that of others. Xiao et al. (2011) reported that *En. sophia* has strong parasitization capacity on both *Trialeurodes variabilis* (Quaintance) and *B. tabaci*. Yang and Wan (2011) reported that *Er. hayati* Zolnerowich & Rose effectively parasitized and fed almost all instar nymphs of *B. tabaci* except the late fourth instar; parasitism on first, second, and third instars were significantly higher than on fourth instar but the utmost prevalence of parasitism was shown on the first instar. Younger nymphal instars were fed on by female parasitoids than older ones. The highest development time was needed for *Er. hayati* when parasitized on the first instar, and intermediate on the second and third instars but lowest on early fourth instar.

Adult parasitoids gain nutrients from the host through feeding insight it, but this process destroys oviposition opportunity on host. Honeydew considered a nutrient rich substitute for the Hemipteran parasitoids. Studies revealed that host secreted honeydew as substitute nutrition increased egg quantity and adult longevity of parasitoids (Burger et al., 2004); whereas host feeding might facilitate female parasitoids to continue the high-quality hydropic egg production that is essential for natural environment. Burger et al. (2005) observed that parasitoids can be acquired advantage and increased their oviposition rate through host feeding compared to honeydew feeding. This task might be relevant under circumstances of high host population density or high mortality of parasitoid adults and if other sources of food may not provide sufficient nutrition for egg production. Almost all parasitoids kill whitefly nymphs either by piercing the nymph with ovipositor following egg oviposition or by piercing the nymph and sucking the body fluids through labium (Shi et al., 2009; Zang and Liu, 2009). The efficacy of the parasitoid performance for controlling whiteflies might be increased by food deprivation for an optimal period prior to release. Zang and Liu (2009) reported that *En. sophia* feeds and parasitizes more *B. tabaci* nymphs during their whole lifespan if the adult parasitoids keep on without food for 6 hours prior to release and found that they live considerably longer than the parasitoids of no food deprivation. Zang and Liu (2010) also examined on *Er. melanoscutus* and *En. formosa* and found that parasitoids depriving food for 6 hours feeds more *B. tabaci* nymphs and parasitizes equal or more number than the parasitoids of continuous feeding.



Studies revealed that parasitoids show preference to oviposit on larger hosts for their immature development suitably though smaller host is better to control the host insect effectively. Luo and Liu (2011) described that the adults of *En. sophia* were larger those were emerged from *T. vaporariorum* rather than from *B. tabaci*. Where all parameters of biological assays except the development time were superior when parasitized larger host than smaller host. Besides, the adult wasps parasitized more nymphs emerging from *T. vaporariorum* than those from *B. tabaci*.

Zang et al. (2011a) have found in their experiment that when they offered *Er. melanoscutus* and *En. sophia* in different densities of *B. tabaci* nymphs the sexed females parasitized and host-fed more number of whitefly nymphs at any host density than unsexed females. Both the females of *Er. melanoscutus* either sexed or unsexed parasitized and host-fed more whitefly nymphs in high host density population. However, sexed females of *En. sophia* fed more whitefly nymphs at high density of host population, but no nymphs were parasitized by unsexed females.

Parasitoids have direct effects selecting the 'right' hosts on the success of reproduction and effectiveness as an agent to control whiteflies. Gelman et al. (2005) stated the physiological and biochemical relations between parasitoids and whiteflies, and they assumed that the parasitoids inject and/or generate bio-chemicals inside their hosts that interfere with the immune system of the host. They also observed that parasitoids maneuver host maturity according to their own needs. Besides, parasitoids must synchronize their own development with that of their hosts, even though if their eggs were laid in fourth instar nymphs.

## INTERACTIONS BETWEEN PARASITIDS AND PLANTS

Whiteflies are polyphagous in nature, and its host plants may mediate the activity of natural enemies noticeably (Inbar and Gerling, 2008; Mansaray and Sundufu, 2010). Plant species and varieties comprise plant attributes including leaf features, volatile compounds, presence or absence of pubescence and/or wax, etc. High dense and rigid hairs on the leaves generate low rates of parasitism (Rajam et al., 1988). Pubescent and trichomes on the leaves reduce parasitism of whiteflies (Gruenhagen and Perring, 2001b; Oster, 1995). *Eretmocerus* species associate greater parasitism rate on hirsute varieties of melon and soybean (Headrick et al., 1996a; McAuslane et al., 2000), indicating that some parasitoid species might be more efficient on certain pubescent plant leaves. Parasitism of the whitefly, *B. tabaci* was poorer on velvetleaf, *Aboutilon theophrasti* Medic than that of on other plants due to discharge of trichome exudates that captured parasitoids (Gruenhagen and Perring, 2001b). Waxy leaf surface also affects parasitism and *Eretmocerus* spp. and *En. pergandiella* had a greater parasitism on reduced wax both in laboratory and field crops than on other plants (Jackson et al., 2000; McAuslane et al., 2000).

## INTERACTIONS AMONG PARASITIDS

Interspecific or intraspecific competitive interactions act on the determining of the function and structure of ecological communities. A plenty of parasitoid species are available in the field. Multiple species of parasitoids attack single host species. Competition among parasitoids could significantly decrease their control efficacy due to inhibition of their reproduction causing from competitive multi-parasitization or heterospecific ovicides. Existence of diversity of parasitoid species might influence negative impact on pest management system if they coexist in the same system for a long period. Stansly et al. (2004, 2005a) reported that *Er. mundus* has higher parasitism efficiency and more ability to

manage *B. tabaci* than *Er. eremicus* Rose & Zolnerowich in coexisting ecosystem of parasitoids. They observed that *Er. mundus* quickly replaced *Er. eremicus* from greenhouses when both of them released together or solely *Er. eremicus*, suggesting that a huge number of *Er. mundus* entered into the greenhouses from the outer area. Collier and Hunter (2001) reported lethal effect of *Er. eremicus* with *En. sophia* reflecting a combination of multi-parasitism and host feeding on parasitized hosts. It is predicted that interruption might happen while *Er. eremicus* directly interacted on *En. sophia* through a lethal interference interaction, for example, with intrinsic competition (multi-parasitism) or facultative hyper-parasitism. These results reveal that competitive interactions among parasitoids may cause displacement of inferior species. Therefore, using of multiple parasitoid species at a time might not be successful to control whitefly (Collier et al., 2002). In contrast, other researchers suggested that competitive interactions among parasitoid species do not interrupt the suppression of host population and, even though, facilitate biological control. It is revealed that though the populations of primary parasitoid were reduced by the interference of auto-parasitoid but had no concomitant disturbance on host suppression suggesting that an auto-parasitoid might be much effective for suppressing host populations and might enhance the whitefly management program (Bográn et al., 2002; Heinz and Nelson, 1996; Hunter et al., 2002; Zang et al., 2011b). In the competitive interactions among parasitoids, one species can affect the other species directly by means of multi-parasitism whereas intra-specific interference or inter-specific interference through host-feeding of the parasitized hosts (Collier and Hunter, 2001; Zang et al., 2011b), while heterospecific ovicides may happen (Collier et al., 2007; Pedata et al., 2002). However, Pang et al. (2011) studied the interspecific competitive interactions of *En. formosa* and *En. sophia* where found that the parasitization rate by *En. formosa* was higher than that of *En. sophia* while used both of them individually. In contrast, the number of parasitized nymphs of *B. tabaci* was reduced considerably when both the *Encarsia* species was applied together either simultaneous or sequential flow compared to individual application. However, dual application of the parasitoids killing more *B. tabaci* nymphs than that of a single application. Therefore, though the offspring of the parasite will be reduced by interspecific competition, but this competition may not affect the efficiency of whitefly control.

Super-parasitism and multi-parasitism delay the developmental time of parasitoids' offspring and decrease larval survivorship, especially in solitary parasitoids. So, discrimination behavior during host selection, i.e. differentiating un-parasitized nymphs instead of parasitized nymphs is important to avoid killing time, parasitization and to minimize the mortality rate of their progeny. Thus, host discrimination behavior in intra-species interaction is frequently observed in parasitoids having solitary in nature to prevent competition among their own offspring, whereas that behavior is just only a few in interspecific interactions (Agboka et al., 2002; Royer et al., 1999). Ardeh et al. (2005) examined the host preference of *Er. eremicus* and *Er. mundus*, and found that super-parasitism were escaped by experienced female. Conversely, naïve females laid eggs on the parasitized hosts, which already parasitized by conspecific females. The hosts parasitized previously by *Er. mundus* females, were not multi-parasitized by *Er. eremicus*. Conversely, *Er. mundus* multi-parasitized the nymphs that had already been parasitized by *Er. eremicus*. Neither *Er. mundus* nor *Er. eremicus* was stronger in case of super-parasitism, even though *Er. mundus* was stronger than *Er. eremicus* in case of multi-parasitism. Huang et al. (2009) examined hyperparasitism of naïve female *En. tricolor* (Förster) through direct behavioral observation using *En. formosa*, a heterospecific parasitoid, and *En. tricolor*, a

conspecific parasitoid as the secondary host at their different larval stages. Encountering rate of recurrence by *En. tricolor* at all larval stages was similar on both host species. Nonetheless, hyperparasitism varied on different larval stages of different hosts, where late larval stages and heterospecific parasitoid, *En. formosa* was most preferred. *En. tricolor* behavior concerned searching, and hyperparasitism was independent of preference to the different nymphal stages of whitefly (*Aleyrodes proletella* L.) (Huang et al., 2009). Similar study was conducted by Zang et al. (2011b), where they stated that *En. Sophia*, an auto-parasitoid, preferred heterospecifics as secondary hosts to produce males. Their study also stated that the females of *En. sophia* parasitized more hosts if they mated with the heterospecifics derived males than the females mated with the conspecifics derived males.

### INTERACTIONS AMONG BEMISIA TABACI, HOST PLANTS AND PARASITOIDS

The traits of host plant may alter interactions between herbivores and parasitoids by influencing the herbivores and parasitoids while infesting on host plants. De Barro et al. (2000) verified that *Er. mundus* originating from cotton (*Gossypium hirsutum* L.) parasitized more *Bemisia tabaci* nymphs or also parasitized more if tested on rockmelon (*Cucumis melo* L.), while lower parasitism was observed in both cases either the parasitoids were originating from tomato or tested on tomato. They assumed that the rough surface of leaves enhance parasitism due to preventing fitting level of nymph underside on the leaf surface which make easier to parasitoids placing their eggs underside the hosts that previously examined by Headrick et al. (1996b). De Barro et al. (2000) also supposed, long, and dense hairs on tomato leaf surface interfere parasitoids movement resulting reduce parasitism that as well stated by van Lenteren et al. (1995).

Herbivores diet of different qualities can mediate differently on the interactions involving plants-herbivores-parasitoids (Harvey et al., 2003). Greenberg et al. (2002) stated that *Er. mundus* developed faster and produced more offspring, and its parasitism and emergence rate was greater on *B. tabaci* than that on *T. vaporariorum* onto tomato whereas, the performance of *Er. eremicus* was similar in both the species except for its female deposited more eggs in *B. tabaci* nymph than that of *T. vaporariorum* nymph. They also reported that *T. vaporariorum* emerged female offspring of both *Er. mundus* and *Er. eremicus* were considerably larger than those of *B. tabaci*. Urbaneja et al. (2007) reported the adult longevity of *Er. mundus* was shorter in the second instar of *B. tabaci* on tomato than those of sweet pepper where the fecundity was more on sweet pepper than that on tomato. They also stated that host feeding incidence of *Er. mundus* was noticeably higher on sweet pepper than that of tomato, and the net reproductive rate ( $R_0$ ) was greater on tomato (63.8) than that of sweet pepper (51.0). Greenberg et al. (2009) described cotton was the most favorable to sweetpotato whitefly, and bean was the most favorable to greenhouse whitefly. They observed that preimaginal mortality of sweetpotato whitefly on cotton was less and developmental time also shorter than that of greenhouse whitefly. Parasitism by *Er. mundus* was greatest on sweetpotato whitefly and least on greenhouse whitefly when both whiteflies were reared on cotton, whereas parasitism by *En. pergandiella* was greatest on sweetpotato whitefly reared on bean or cotton. Emergence of *Er. mundus* was the greatest from sweetpotato whitefly on cotton, where emergence of *En. pergandiella* was noticeably greater than that of *Er. mundus* among host plants.

Release rate of parasitoids mostly depends on plant host species, growth stage of plants, parasitoid species, herbivore density, field condition and area of crop field. At low density of herbivore, parasitoids release periodically at lower rate showed better performance than



once release at higher rate (Gu et al., 2008). Stansly et al. (2005b) observed on pepper plants that whitefly populations, both nymphs and adults were reduced over 90% when released parasitoids at both high and low rates (6 *Er. mundus*/m<sup>2</sup>/week, 1.5 *Er. mundus*/m<sup>2</sup>/week, respectively). Whitefly densities of both nymphs and adults were decreased exceeding 95% on tomato plants due to higher rate of parasitoid initiation but about 54% nymphs and 69% adults at the lower rate. Similar results were described by Bellows et al. (2006), whereas Qiu et al. (2004) reported 3-5 females of *Eretmocerus* sp. per cucumber plant is optimal for controlling of *B. tabaci*. However, Lopez and Andornoa (2009) observed that at the rate of two *Er. mundus*/plant/week was sufficient to manage whitefly population on pepper but if parasitoids had to be released three times achieving the best pest suppression with 84% of parasitism.

## CONCLUSION

The whitefly, *B. tabaci* establishment onto new host plant is mainly considered by feeding as well as oviposition preference which is mediated by plant leaf features and chemicals inside. Moreover, natural enemies with abiotic factors play a fundamental role to adapt whitefly on host plants. Parasitoids prefer larger host to oviposit and show better performance but more efficient on smaller host to control. A large number of researches revealed, parasitoids usually prefer earlier host stages to feed, and only some studies illustrated that older host stages are preferred. Some parasitoids have higher parasitism ability, and their efficiency depends on augmentation period. Therefore, during application of parasitoids to control whiteflies biologically, we have to be emphasized on locally available parasitoid species, sequence of parasitoid initiation, intra-specific or inter-specific competitive interactions of parasitoids, host plant species, whitefly population density and nymphal stages, and finally field condition. To develop the best strategies for whitefly management on vegetables and other field crops, the careful thought should be given to the interactions among three components including whitefly-host plant-parasitoid.

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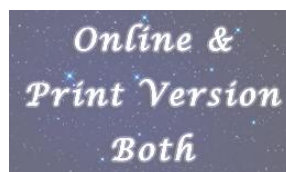
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