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Asian Citrus Psyllids (Hemiptera: Psyllidae), Its Vectored Disease "Huanglongbing" and Its Eco-Friendly Management

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Abstract

Citrus is being hosted by a wide range of insect pests, causing approximately 25 percent yield losses and Asian citrus psylla has a major share of more than 80%of these losses. The Asian citrus psylla (ACP), *Diaphorina citri* K. (Homoptera: Psyllidae) was firstly described in Taiwan and afterward it was found in Indo-Pak region and now is widely distributed in south Asia and several countries of the world. ACP was primarily observed in tropical and subtropical regions of Asia and later on reported from more than twenty-one geographical areas of the world including south Asia. In addition to direct damage to plants through sucking cell sap and lead to defoliation, ACP is the vector of a fatal disease called "citrus greening" or huanglongbing (HLB). A number of bio-intensive technologies have proved their effectiveness in psyllids management, likewise predators, parasitoids and pathogens, but wherever psyllids occur, they are usually attacked by some common predators like lady beetles, syrphid flies, lacewings and spiders.Present review study is aimed to provide maximum information on ACP, HLB and eco-friendly practices for management of psyllids and their vectored disease.

1 Introduction

There are around 15-20 major insect pests attacking on citrus trees including, fruit fly, whitefly, thrips, leaf miner, scales, mealy bug, caterpillars, fruit sucking moths and Asian citrus psylla. These insect pests cause approximately 25 percent yield losses, out of which citrus psylla shares 83-95% as surveyed in central India (Shivankar & Singh, 2006). The Asian citrus psylla (ACP), *Diaphorina citri* K. (Homoptera: Psyllidae) firstly found in Taiwan Kuwayama (1908) and afterward found in Indo-Pak region (Hussain & Nath, 1927). Now is widely distributed in south Asia and several countries of the world (Khan et al., 2014).

Asian citrus psyllid is a serious pest of citrus in several other countries and vector of a fatal disease called "citrus greening" or huanglongbing. *D. citri* was primarily observed in tropical and subtropical regions of Asia and later on reported from more than twenty-one geographical areas of the world including south Asia (Halbert& Nunez, 2004).Greening disease in citrus has destroyed several industries in Asia and Africa (Manjunath et al., 2008). *D. citri* is a pest of citrus and closely related citrus plant families. It causes direct damage to plants through sucking cell sap and resultant new shoots do not expand and develop normally which ultimately lead to defoliation (Elizabeth et al., 2005).

A number of bio-intensive technologies have proved their effectiveness in pest management, the major components in this concern are the natural enemies; likewise predators, parasitoids and pathogens. Throughout the world, *D. citri* is being subjected to the species complex of biological control agents varying in different geographies, but most important are lady beetles, syrphid flies, green lacewings and spiders (Hall, 2008). Wherever psyllids occur, they are usually attacked by some common predators like lady beetles, syrphid flies, lacewings and spiders (Aubert, 1987; Michaud, 2001, 2002, 2004; Gonzalez et al., 2003).

The lady beetles of family Coccinellidae have been successfully evaluated as a predator against Homopterans (aphids) and many other economically important insect pests of crops in Pakistan (Fayyaz, 1998). However,there is quite little information about the extent that how much these predators reduce the infestation of *D. citri*.Lady beetles are found to be the most effective natural enemies of *D. citri* in Florida (Michaud, 2002, 2004); however, there is a need to evaluate the effectiveness of these predators worldwide in citrus culture. The citus groves which are producing organic fruits are trending to apply natural enemies of pests along with the use of bio-pesticides. (Tengerdy & Szakacs, 1998; Rausell, et al., 2000).Although using insecticides is a cheaper way to control psyllids in citrus orchards, but injudicious use of broad spectrum insecticides has led to environmental pollution and health hazards through contamination of food chain. At the same time *D. citri* is becoming resistant to several synthetic insecticides, therefore it is challenge of the day to adopt some alternative means of pest management that would be effective and safe to environment and human health (Khan et al., 2014). Nature is exercising its check on insect pests by the phenomenon known as natural control; this is without interaction of human. Nature keeps the harmful insects below economic threshold levels. Host plant and their natural enemies comprised a triangle of interaction, when the harmful effects of any organism migrated to others; then third party natural enemy counts its check on that harm.

Nature is maintaining a huge number of predators and diversity, but only few species have been explored for mass production. It is due to limited availability of predators species identified which can be reared economically in laboratories. But today's scientists are in struggle for the conservation of natural enemies instead of rearing. Bio insecticides (botanicals & bacterial insecticides) have been developed as a safe and effective control measures against psyllids. These insecticides encourage natural enemies and can also act as environment friendly management practices in citrus orchards (Khan et al., 2014).

2 Asian Citrus Psylla (ACP) *Diaphorina citri* Kuwayama

Several species of psyllids have economic importance as agricultural pests and cause damage through direct feeding on plants and disease transmission. Psyllids may be monophagous or oligophagous and attack on much of dicotyledonous plant species (Burckhardt, 1994). In Pakistan, the problem of *D. citri* and greening disease of citrus has not been addressed as of much importance; however, in addition to psyllids, some environmental factors and disease susceptible rootstocks are also among the causes of greening problem (Hoddle, 2012).

In Florida, invasion of citrus psylla and its vectored disease "huanglongbing" reduced an average of about 10 percent area of citrus production. This reduction of citrus acreage resulted in job losses of approximately 8257 in numbers, revenue reduction of $ 2.7 billion (US) and decreased $ 1.8 billion (US) worth of economic activities related to citrus work force (Hodges & Spreen, 2012).

2.1 Origin and Distribution of Asian Citrus Psylla

The ACP was first described in Taiwan (Kuwayama, 1908), while in Asia it was initially found in Punjab (Pakistan & India) and then all over the citrus growing areas (Husain & Nath, 1927). Asian citrus psylla is native to Asia and has spread throughout tropical and subtropical citrus growing areas and has also invaded Middle East, Central & South America, Mauritius and Madagascar (Wooler, et al., 1974; Etienne & Aubert, 1980; Burckhardt & Martinez, 1989; Bernal, 1991; Etienne, et al., 2001; Halbert & Nunez, 2004; Cardwell-Grafton, et al., 2005; Hall, et al., 2008). In Florida, USA it was introduced in 1998 (Halbert, 1998; Knapp et al., 1998).

In favorable environmental conditions the population of ACP can reach its extreme level. Ahmad, (1961) reported an average of 41561 adult psyllids per citrus tree. Similarly Aubert (1987) reported 200 psyllid adults/m^2 on citrus jasmine (*Murraya paniculata*) plants in Reunion Island, by using D-VAC machine for sample collection. Several studies regarding population dynamics of ACP in Pakistan indicated the peak population during the month of August and April. Environmental factors have no significant effect on psyllids population (Ahmad et al., 2004).

2.2 Host Plants of Asian Citrus Psylla

Psyllids attack several economically important plants i.e. carrot, apricot, legumes and eucalyptus (Kainulainen et al., 2002; Jarausch et al., 2001; Finlay-Doney & Walter, 2005; Geiger & Gutierrez, 2000; Hodkinson et al., 2001; Purvis et al., 2002; Daane et al., 2005). Similarly multiple plants in family Rutaceae are considered as good hosts of ACP (Halbert & Manjunath, 2004; Halbert, 1998; Tsai et al., 2000; 2002).

2.3 Biology of Asian Citrus Psylla

Female lays as many as 500-800 eggs in her natural life (Catling, 1970). Female of ACP only lays eggs on unfurled new flush (Huang et al., 1999; Rogers et al., 2010), usually high density of eggs on 1st leaf (Yang et al., 2006). The eggs of ACP are orange/yellow color (0.3 mm) and hatch in 4-8 days at temperature of 25-28°C. Oviposition is directly associated with temperature and under ideal conditions (20-28 °C), about 300-750 eggs may be deposited by a single female in its life period of30-50 days-. The temperature above 28°C may reduce the fecundity and life span of female psyllid (Tsai & Liu, 2000). It has been observed that the life span of female may be shortened if egg laying process completed in early age of adult, therefore females take long period for egg laying (Yang et al., 2006). When new shoots are not fit for egg laying then the females either remain on mature leaves of host plant, or find new host with new flushes for oviposition (Rogers et al., 2010).

Asian citrus psylla has five nymphal instars which complete their development in 11-15 days under suitable temperature. The body length of these instars range from 0.3 to 1.7 mm in size. The orange/green color nymphs have circumanal glands secreting waxy substance in addition to honeydew from anal part (Tsai & Liu, 2000). Nymphs are inactive to move here and there but it is not necessary that they cannot move to neighboring twigs, although they remain on immature leaves during initial stages and dispersed in latter instars (Yang et al., 2006).

The adults ACP are 3-4 mm in length, wings with dark bars across top and bottom, showing an X shaped pattern on lateral view used to resting or feeding alighted at angle of 45^{o} on the substrate (Halbert & Manjunath, 2004) and adult psyllids may be appear dusty (Knapp et al., 1998). On disturbance they become active at certain temperatures, start jumping and take a short flight. However psyllids are not good flyers and usually found on warm and shady foliage sites within the tree canopy (Yang et al., 2006). Adult females have 2-3 day pre-oviposition period and after mating start oviposition in 1-2 days (Wenninger& Hall, 2008). Female attracts the male through volatile sex pheromone (Wenninger et al., 2008). Asian citrus psylla completes its development in 15-47 days, depending habitually upon the temperature. Its population densities recorded have been directly related to flushing pattern of host plant and correlated with abiotic factors of the area (Tsai et al., 2002). Outbreaks of ACP can happen through the year depending upon emergence of new flushes and temperature (Hall, 2008).

2.4 Direct Damage to Citrus Plants Caused by Asian Citrus Psylla

Psyllids suck large quantities of plant phloem and encourage sooty mold by excreting excess of honeydew and waxy material at the feeding place (Aubert, 1987; Triplehorn & Johnson, 2005). High density of psyllids cause direct damage to plant and excrete copious amount of sugary material causing partial as well as complete defoliation of infested plants (Aubert, 1987; Geiger & Guiterrez, 2000). Plant leaves sucked by ACP become curly and notched, in addition to death of new sprouts. In case of heavy infestation of nymphal stages, whole terminal has been observed to be damaged (Michaud, 2004).

3 Greening Disease of Citrus

Lin & Lin (1990) studied that greening disease of citrus or huanglongbing (HLB) was originated in north-eastern part of Guangdong, China. They also stated the possibility of HLB is linked with geographic distribution of ACP, a primary vector of HLB in Indian subcontinent. Among sucking insect pests of citrus, psyllid is a serious pest and primary vector of HLB and considered as world's most distressing problem in citrus. The causal organism of HLB is a bacteria *Candidatus liberibacter asiaticus* (Garnier et al., 2000;Shivankaret al., 2000; Elizabeth et al., 2005; Teixeira et al., 2005), that is Asian and associated with citrus production (Garnier & Bove, 1996).

During plant analysis the greening pathogen found in sieve tubes of infected plants and afterward they acquired and transmitted by ACP during feeding activities (Garnier & Bove, 1983). The transmission of this pathogen to citrus plants is associated with salivary secretions of ACP (Aubert, 1987). If an adult ACP feeds for 30 minutes on an infected plant it acquires HLB bacterium (Halbert & Manjunath, 2004). Infected adult psyllids transmit the phytopathogenic bacterium through their sucking habits to healthy trees and symptoms of the disease may appear within several days even in months, however this disease may be controlled by suppressing its vector psyllids (Bove, 2006). Acquiring of greening bacterium can also be done by any of nymphal stage of psyllid, but only 4^{th} and 5^{th} instar can transmit disease to other plants (Inoue et al., 2009).

Greening symptoms on citrus plants appear on leaves as yellowing of veins, molting of leaves and fruit developed unpleasant taste (Da Graca, 1991), resembling zinc deficiency (Halbert&Manjunath, 2004). Use of Polymerase Chain Reaction (PCR) may allow rapid detection of the *Candidatus liberibacter asiaticus*, in infected citrus and in the vector as well (Korsten et al., 1996; Hoy et al., 2001; Hung et al., 2004). Once infected the mature plants starts defoliation and die back within few years and stop production (Brlansky & Rogers, 2007).

Greening pathogen acquisition by psyllids is related to different factors. Capoor et al. (1974) concluded that 45-50% of a plant became disease infected, if a psyllid carrying pathogen fed on a healthy plant for one minute and full plant will become diseased if it fed on plant for half an hour. Inoue et al. (2009) examined the acquisition of pathogen through PCR assays and found that 88% of adult psyllids become infected if they fed on diseased plant for 24 hours. Rogers et al. (2010) conducted real time PCR assays and found that 20-30% of adult psyllids acquired HLB bacterium that had fed on diseased plants.

Su-(2008) reported that 5% or fewer adults acquired bacterium by feeding a diseased plant for a period of 24 hours. Bonani et al. (2008) found that, if psyllids fed on mature diseased plants did not acquire the pathogen, whereas if they fed on young diseased plant the half of psyllids population acquire bacterium. The differences in acquisition and pathogen transmission time reported may be due to the variation in experimental protocols or due to differences in population dynamics of ACP in different regions or host plant suitability.

4 Insecticidal Management of Asian Citrus Psylla

4.1 Use of Synthetic Insecticides

Citrus psylla may be controlled by spraying some insecticides at different intervals. Injection of trees with tetracycline, antibiotics showed good results to control greening disease in citrus plants (Bindra et al., 1974).Application of synthetic chemicals and petroleum oil are considered good as source for ACP suppression (Rae et al., 1997). Fenpropathrin, imidacloprid and aldicarb are recommended for ACP control and the most effective application of foliar insecticides is during the early flushing season. Usually at the time when nymphal population is at highest level and more psyllids can be killed (Browning et al., 2006; Stansly & Rogers, 2006; Rogers & Timmer, 2007).

In Florida use of insecticides is the major component for controlling ACP in citrus (Rogers et al., 2010). Soil treatment of aldicarb (Temik®) @ 5.6 kg/ha to mature citrus trees applied 2-3 months before spring can suppress psyllids through season, additionally it also showed less effect on natural enemies of psyllids (Qureshi & Stansly, 2008). Some new chemistry synthetic insecticides have shown good results in controlling ACP, but have some limitations to young plants if treated in soil (Qureshi et al., 2009). In spring season plants start to emerge new twigs that attract ACP and they initiate to oviposition. If adult psyllids are suppressed by using some selective insecticide during their overwintering before emergence of new shoots, it would be an effective measure to safeguard plants (Qureshi & Stansly, 2010). Today it is a common practice to use insecticides for vector management of greening disease of citrus (Setamou et al., 2010; Tiwari et al., 2011) but due to similar mode of action of different insecticides, ACP is developing varying levels of resistance to these chemicals. There are also evidences of detoxifying enzymes in field populations of ACP regarding insecticide resistance (Tiwari et al., 2011).

4.2 Insecticidal Residue in Citrus and Their Environmental Threats

The use of organochlorine insecticides is decreasing due to their toxic effects in diet for long time (Jaga & Dharmani, 2003). In human being increasing percentage of different diseases is due to their exposure to insecticides either directly or in shape of residues (Ascherio et al., 2006). Most of the synthetic insecticides have toxic effects and are dangerous to human health. These insecticides when applied against some pests; they remain in shape of residues in fruits (Hussaina & Siddique, 2010).

4.3 Use of Bio-Insecticides against Asian Citrus Psylla

Some medicinal plants are found to be poisonous for insects and pests (Sahaf et al., 2007; Roger, 1997). It is need of the day to explore economical and effective bio-insecticides for house hold, agriculture and human disease vector control. The plant based insecticides are preferred over synthetic insecticides because of their little or no negative effect on the agro-ecosystem (Jacob et al., 2000; Greenburg, 2005; Isman, 1999). Parasitizing ability of most of the parasitoids is affected by insecticides, which effect on parasitization, mortality and anti-feeding activities. However neem based insecticides have minimal effect on these parameters of a parasitoid, although aqueous solutions are less toxic than oils on natural enemies (Condor-Golec, 2007).

Total dependency on synthetic control is not justifiable for psyllid control. It is noted that injudicious use of pesticide has not prevented the orchards from psyllid attack. Also the use of insecticides incurs high costs along with harmful effects on citrus ecosystems (Wang, 2002). The insecticidal importance of neem has been reported against more than 200 species of insect pests, considering its no or negligible residues to human and environment (Ascher, 1993; Raguraman & Singh, 1999). Neem oil and insect growth regulators applied 2-3 times with the interval of 10-15 days were found to be effective against citrus psylla (Dahiya et al., 1994; Nakano et al., 1999; Shivankar et al., 2000).

Effects of a neem (4.5%) based biopesticide, assessed against the ACP showed significant repellant effect toward psyllids, with no influence on their oviposition. Psyllid nymphs were found susceptible to azadirachtin and stopped ecdysis has been observed even after four days of treatment. Neem showed no phytotoxic effects on plant and within seven days of treatment all of the psyllid nymphs were found dead (Weathersbee & McKenzie, 2005).

A longer and strong effect against ACP has been observed for the treatments of horticultural spray oil (Oil-435), spirotetramat (Movento® 240 SC), tolfenpyrad, abamectin + thiamethoxam (Agriflex®), and diflubenzuron (Micromite®) all applied with Oil-435. Significant psyllids suppression was observed for all of these treatments for 17 days. During another experiment psyllids were suppressed for 5 weeks for treatments of 435 Oil and Sivanto (300/ac) applied alone and Sivanto (200, 300 or 400 ml/ac rate), spinetoram (Delegate®), spirotetramat (Movento®) all with Oil-435, and imidacloprid (Provado®) and Sivanto (300ml/ac). Flush provided some protection from contact insecticides to ACP adults, however more nymphs were suppressed as compared to adult psyllids. During growing season selective insecticides provide required suppression of ACP with less damage to bio-control agents. These agents may be at risk if broad spectrum insecticides are applied at that time (Qureshi et al., 2011).

Psyllid adults and nymphs exposed to JMS Stylet Oil®, M-Pede® an insecticidal soap, Entrust0® and Aza-Direct® provide more than 80% mortality of psyllids with in 72hrs of observation in laboratory conditions (Qureshi et al., 2013).Confidor® (imidacloprid), Movento® (spirotetramat) and Radiant® (spinetoram) showed 77-95% mortality of psyllids, while Datura (tropane) and neem (azadirachtin) showed 31-60% mortality of psyllids. These botanicals and selective insecticides were applied at commercially recommended doses using leaf dip and spray methods of bioassay (Khan et al., 2013).

5 Biological Control of Asian Citrus Psylla

For long term and sustainable management of invasive insect pests, biological control is considered as an important defensive measure. The bio-control approach is intended to conserve predator complex of arthropods against the insect pests in cropping ecosystem (Mills, 1994). Eggs, nymphs and adults of citrus psyllid are consumed by a variety of bio-control agents. Most active predators are ladybeetles, lacewings, spiders and syrphid fly (Michaud, 2004). During 300 B.C. Chinese used ants as bio-control agents for suppression of insect infestations in citrus groves and it was first step in biological control of citrus insect pests (Pedigo & Rice, 2009).

Natural enemies can regulate the infestation caused by ACP, which is considered as major threat in Kinow production in Pakistan (Hoddle, 2012). Studies in different geographic regions indicated that ACP is consumed by many natural enemies, including lady beetles, syrphid flies, green lacewings and spiders. These are active and efficient predators of citrus psyllid in citrus growing areas. Some studies showed more than 90% of immature psyllids did not become adults as they were consumed by these predators if present on infested plants (Manjunath et al., 2008; Rogers et al., 2010) and predatory mites. Juan-Blasco et al. (2012) observed 80% decreases in psyllids population in glass house experiment on citrus plant where predatory mites *Amblyseius swirskii* were released.

In addition to predators, parasitoids are also a vital component for bio-control in reducing psyllid population in citrus orchards. An experiment was conducted by releasing two parasitoids, *Tamarixia radiata* Waterston and *Diaphorencyrtus aligarhensis* in Florida against ACP. It provided good parasitism in psyllids; formerly it has successfully reduced psyllids in Reunion Island (Etienne &Aubert, 1980) and in Taiwan (Chien & Chu, 1996). Female of *T. radiate* feeds on the initial instars of ACP and oviposit underneath of the 5^{th} instar (Chu & Chien, 1991). At temperature of 25^{o}C a female can lay 300 eggs (Chu & Chien, 1991; Etienne et al., 2001). The *T. radiate* is a parasitoid of ACP and is native to Asia. Feeding and oviposition of a female *T. radiata* may depend on host plant behavior and a single female can destroy 500 nymphs of ACP during her life span (Chien, 1995). It has been observed in laboratory studies that, *T. radiata* can parasitize 90% of offered population of nymphs (Aubert, 1991; Skelley & Hoy 2004). Qureshi et al. (2009) reported varying levels of citrus psyllid control in presence of *T. radiate* evaluated in Florida citrus orchards.

5.1 Lady Beetles as Bio-control Agents of Asian Citrus Psylla

A trend has been seen that a huge quantity of adult coccinellids has been collected from mountainous area of California and sold to commercial groves for mass release in United States and Canada (Obrycki & Kring, 1998). The predation by the coccinellids depends upon seasonal variations, which usually occur less in late season and more in early egg laying season. The coccinellids released in field with relation to seasonal variation showed a positive effect on their predatory potential against the prey (Bashford, 1999). The convergent lady beetle, *Hippodamia convergens* Guerin-Menevellie has been observed as a significant predator of most of insect pests such as aphids, scales and mites (Michels et al., 2001; Michaud & Qureshi, 2005) and considered as one of the most common predator in North America (Van-Lenteren, 2003) and also rest of the world.

With the increase of psyllids, an increase in population of a beetle *Olla v-nigrum* Mulsant is recorded on citrus trees (Michaud, 2001). A positive relation between population of psyllids and abundance of coccinellids has been recorded having an important role as natural enemy of psyllid in citrus orchards (Plukeet al., 2005). Lady beetles, *Olla* and *Harmonia* spp. are considered as most important predators of nymphal stages of citrus psylla and it is observed that, in some shoots of citrus plants, much of the immature psyllids were consumed by lady beetles, regardless of the predators stage (Elizabeth et al., 2005).

In China some experiments showed that, the lady beetle *Coccinella septempunctata* Linnaeus is extensive feeder of psyllids (Yang et al., 2006). In Florida, the lady beetles; *Curinus coeruleus* Mulsant, *O. v-nigrum*, *Harmonia axyridis* Mulsant, (Pallas), *Cycloneda sanguinea* Linnaeus and *Exochomus children* Mulsant are recorded as most common spiecies as a predator against citrus psyllids (Michaud, 2004; Qureshi & Stansly, 2007). In addition to the psyllids, coccinellids do predation on wide range of homopterans like aphids. However their response to psyllids infestations found to be efficient and these generalist predators may cause 80-100% mortality of psyllid eggs and nymphs (Qureshi et al., 2009). Although most of the species of coccinellids are not available commercially for mass release, however strategies for their natural population conservation are being developed (Qureshi & Stansly, 2009, 2010).

5.1.1 Lady Beetles in Pakistan

Studies conducted in some cropping and forest areas of Faisalabad, Pakistan indicated 22 species of coccinellids that are actively participating as bio-control agents (Zahoor et al., 2003). A survey conducted in District Chitral of Pakistan, revealed 12 species of predatory

Coccinellids. The species; *Coccinellinae latreille, C. septempunctata*, *Hippodamia variegate* Goeze, *Calvia punctata* Mulsant, *Aiolocaria tetraspilota*, *A. hexaspilota*, *Oenopia conglobate* Linnaeus were already reported in Pakistan And *Chilocorus circumdatus*, *Calvia punctata*, *Adalia bipunctata*, *Priscibrumus uropygialis*, *Macroilleis halyziahauseri* and *O. conglobate* are noticed first time (Khan et al., 2006). So a good fauna of lady beetles (coccinellids) is present in Pakistan that can be conserved and be utilized as effective bio-control agents against a wide range of insect pests.

5.1.2 Two Spotted Lady Beetle (Adalia bipunctata Linnaeus)

Two spotted lady beetle is distributed through Asia, Europe and North America (Hodek, 1973; Hodek & Honek, 1996). Similar to seven spotted lady beetle, *A. bipunctata* is an important predator of aphids. The orchards maintain a good population of coccinellids for instance *A. bipunctata* and *Stethorus punctillum* that breed and hibernate well in woody plants. In south East Kazakhstan the release of field collected *A. bipunctata* reduced much of the aphid infestation in orchards (Hodek, 1973). *Adalia bipunctata* is also distributed all over Pakistan and more density has been found in forest areas than the cropping areas (Zahoor et al., 2003; Khan et al., 2006).

5.1.3 Biology of Adalia bipunctata

The eggs of *A. bipunctata* are yellow orange color with size of 0.4 mm, laid in groups of 10-40 usually on underside of leaves. Oviposition last for about 30 days and a single female during her life span can lay about 500 eggs. Larval development completes in four instars; 1st and 2nd grey/black in color, 3rd and 4th black colored with yellow/orange stips and also distinguished by their size. Pupa looks cylindrical and orange color with black spots. Adults are 5-8 mm in length, bright red appearance. The pronotum is black with distinctive patterns which are different in male and female. Most of these beetles have two spots on fore wings but at the same time *A. bipunctata* is example of poly morph forewings with more than 15 color pattern in a single species. Development of *A. bipunctata* depends upon temperature and at 25°C life cycle completes in 19 days, the adult individuals may live for 56 days (Hodek, 1973).

5.1.4 Predatory Potential of Adalia bipunctata

Adalia bipunctata when provided with aphids (*Aphis fabae* Scopoli and *Aphis pomi* De-Geer), it consumed an average of 30.9, 27.33, 38.44 and 105 aphid nymphs by 1st, 2nd, 3rd and 4th instars respectively through their developmental time. While, adult consumption was recorded 19.43-61.14 per day (Tanja, 2006). Ten aphid species were evaluated as essential prey for *A. bipunctata* and the aphids *Eucallipterus tiliae* and *E. betulae* were found most suitable prey. Beetles fed on these preys showed good larval development, less larval mortality and more adult fresh weight (Kalushkov, 1998). Presently no study has been conducted regarding predation of *A. bipunctata* against citrus psyllids.

5.2 Brown Lacewing (Sympherobius barberi Banks)

Hemerobiidae family has many species of brown lacewing that act as natural enemy of a wide range of small insect pests. This family contains around 560 described species in 27 genera (Oswald 1993, 1994; New 2001; Grimaldi& Engel, 2005).

5.2.1 Biology of Sympherobius barberi

Females of *S. barberi* lay non-stalked eggs, usually laid singly and look similar to eggs of syrphid fly but have small nobe on tip. Larval stage comprised of three instars, active 1st instar can run fast, moving its head side to side during wondering for food. The 2nd and 3rdinstars are relatively lazy for movement. White cocoon of double structure constructed in protected areas later on used for pupation. Adults are soft-bodied insects with membranous brown forewings, hind wings are transparent and light brown body color. Brown lacewings undergo complete metamorphosis process (MacLeod & Stage, 2005).

5.2.2 Predatory Potential of Sympherobius barberi

Most of soft bodied insects and their eggs are considered as best choice for members of family hemerobidae. A larva of brown lacewing *Micromus posticus* Walker, can consume 41 aphids during its life (Cutright, 1923). In Texas, *S. barberi* has been mass reared for control of citrus mealy bug *planococcus citri* Risso. In Florida, ten species belonging to four genera of family Hemerobiidae have been recorded. Both adult and larva of *S. barberi* are efficient predator upon a wide variety of small insects and their eggs including mealybug, aphid, small caterpillars, psyllid eggs and nymphs (Macleod & Stage, 1981). Larval stage of hemerobiids prey on insect pests of agriculture, horticulture and forests (Monserrat et al., 2001). Hyper predation on brown lacewings may occur in presence of spiders (Cutright, 1923; Smith, 1923; Smith, 1934; MacLeod, 1960), however due to its activeness and special character of adults forewings dual layer of hairs, that make it water resistant, enhance its flying capacity and predation activities (Watson et al., 2011).

Although these brown lacewings are considered as good biological control agents and some species have been used for this purpose, but limited work has been done. Foot Hill Agriculture Research Inc. California is rearing mass production for commercial use of *S. barberi* for control of the citrus insect pests.

6 Conclusions

Injudicious uses of broad spectrum synthetic chemicals have a negative role through contamination of ecosystem and posing health hazards to end consumer. Therefore it is need of the day to design the sustainable pest management strategies with reference to environment friendly approaches. Ecologically Based Integrated Pest Management (EBIPM) is the best solution to save the environment and conservation of natural enemies. So to manage the population of a serious pest of citrus, Asian citrus psyllids in citrus orchards by conserving the bio-control agent and keeping the environment friendly for predators and the end user these practices must be included in IPM modules.

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