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Bio-ecology and Management of Citrus psylla, *Diaphorina citri* Kuwayama on Citrus - A Review

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A B S T R A C T

The citrus psyllid, *Diaphorina citri* Kuwayama, is the most important pest of citrus worldwide because it serves as a vector of *Candidatus Liberibacter* species that cause citrus greening disease. The nymphs and adults suck cell sap causing curling of leaves, defoliation, flower drop and death of branches from t to downwards which is known as die back. The peak population found usually in March-April and August-September. Among the parasitoid, *Tamarixia radiata* is promising and needs to be introduced and chemical control is the primary management strategy currently employed, but recently documented decreases in susceptibility of *D. citri* to several insecticides illustrate the need for more sustainable tools. Herein, we discuss recent advances in the understanding of *D. citri* seasonal abundance and behavior, pathogen transmission biology, biological control, and chemical control goal is to point toward integrated and biologically relevant management of this insect-pest.

Introduction

The productivity and quality of citrus is severely affected by several factors; insect pests being one of them. Great diversity of soils and agro ecosystems in which citrus is grown in Asia are rich sources of insect fauna. In India 250 species of insects have been reported on various citrus species (Pruthi and Mani, 1945; Wadhi and Batra, 1964). A number of insect pests attack citrus plants both in the nurseries as well as in the orchards inflicting heavy economic losses. Majority of the insect pests occur at the new flush stage and damage the new growth thereby hampering the plant development. Among the insect pests, citrus psylla, *Diaphorina citri* Kuwayama (Hemiptera: Psyllidae) is considered the most destructive pest causing heavy losses in citrus growing areasand the losses ranged from 83-95 per cent (Randhava, 1974). Both nymphs and adults of psylla suck the cell sap from flower buds, leaves and young shoots and result in leaf distortion, curling and complete defoliation or shedding of flower and leaves. This insect has become immensely important because it is the vector of the bacteria, *Candidatus Liberibacter asiaticus* that causes citrus greening disease that is restricted to the phloem vessels (Gravena, 2005). No control method will totally eliminate psyllids and the risk of pathogen transmission within a grove. Implementation of IPM practices to suppress the overall psyllid population will likely help slow the spread of the disease and maintain the economic feasibility of citrus production. Development of such a program requires knowledge of the biology of the pest, including factors that regulate psyllid populations, and available control options. The current review provides subsequent developments in knowledge of the biology, ecology, and management of *D. citri*.

History and distribution

The citrus psylla, *Diaphorina citri* Kuwayama is currently one of the most important insect-pest and as a vector of destructive greening disease of the world citriculture. Tirtawidjaja *et al.,* (1965) demonstrated that the vein-phloem degeneration disease of Indonesia is transmitted by *D. citri.* Salibe and Cortez (1966) published preliminary evidence that *D. citri is* the vector of leaf mottling and this was later confirmed by Celina *et al.,* (1966) and Martinez and Wallace (1967). It was first reported in 1907 from Taiwan and is now well distributed across several countries (Halbert and Manjunath, 2004). Capoor *et al.,* (1967) have shown convincingly that *D. citri* is an efficient vector of greening disease of citrus in Indian continent and (Boykin *et al.,* 2012) was first reported from the continental USA (Florida) in 1998 and now occurs from Florida to California. The geographical origin of *D. citri* is thought by some to be Southern Asia, probably India. Mead (1977) listed the Far East as the geographical origin of the psyllid. The Asian citrus psyllid is found throughout Asia, in the Saudi Arabian Peninsula and in some islands in the Indian Ocean. It is known to occur in China, India, Myanmar, Taiwan, Philippine Islands, Malaysia, Indonesia, Sri Lanka, Pakistan, Thailand, Nepal, Hong Kong, Ryukyu Islands, Afghanistan, Saudi Arabia, Réunion and Mauritius (Mead, 1977 and Halbert and Manjunath, 2004). The psyllid was known to be in Brazil (Mead, 1977) since the 1940s (Costa Lima, 1942). During the 1990s, *D. citri* invaded the West Indies, Abaco Island, Grand Ahama Island and Cayman Islands (Halbert and Nunez, 2004), and it was found in Florida during 1998 (Tsai and Liu, 2000). During 2001, the psyllid was found in the Dominican Republic, Cuba (Halbert, and Nunez 2004), Puerto Rico (Pluke *et al.,* 2008) and Texas (French *et al.,* 2001). It has recently been reported in many new areas in the Americas including Mexico, Venezuela and Argentina (Halbert and Nunez, 2004).

Population dynamics of citrus psylla in relation to abiotic factors

The climatic conditions in citrus growing areas are characterized by mild temperature and high humidity, which favors the pests and disease incidence. In the past few decades the growers are facing a high incidence of pest and also the citrus decline or dieback. Husain and Nath (1927) reported that peak period of psyllid infestation was almost synchronous with the flush of fresh shoots in India. They had further reported that the pest becomes active by the end of February and its population rapidly increases during March and April. The adults predominated during May and June and fresh colonies develop in July. It begins to disappear during the middle of October and occurs only in small numbers thereafter during December and January and seasonal incidence of *D. citri* on orange in some districts of Punjab and recorded maximum population during September and November, while decline in population was noted December-January (Singh and Singh, 1990). There were four peaks of pest population of *D. citri* on citrus which occurred during March, June-July, August-September and October-November (Atwal *et al.,* 1970). Mild winter followed by a favorable spring provides suitable conditions for a high population build up. In Florida, populations of adult, *D. citri* in orange jasmine (*M. paniculata*) and potted grapefruit (*C. paradise*) were continually present with peak populations during June-July, September-October, December, and February-April (Tsai *et al.,* 2002). Teck *et al.,* (2011) found that *D. citri* population fluctuates throughout the year on citrus honey mandarin but nymphs were generally higher during the rainy season from October to January than during the dry season and adult and egg population peaks for a short period generally coincided with three annual flushing cycles in August-September, February-March and June-July between March 1998 and December 2000 in Sarawak.

Sahu and Mandal (1997) at Mohanpur, West Bengal observed that the pest remained active from the first week of June to the end of July, second week of September to the end of December, and from second week of February up to the end of April, during which the population of *D. citri* peaked 3 times (end of June, end of November and mid-April) on *Citrus medica*. Moderate climatic conditions coupled with the flushing of citrus trees favoured the development and activity of nymphs, while extremes of both high and low temperatures, low relative humidity and high rainfall were detrimental, whereas, Arora *et al.,* (1997) at Abohar, India reported that psyllid remained active more or less throughout all three years of their study and there was a positive correlation between temperature and psyllid population and a negative correlation with relative humidity. In case of nymphal population, two peaks were observed, one during the second fortnight of March or first fortnight of April and the other during the first fortnight of September/October, which coincides with the occurrence of fresh vegetative flushes. Chavan and Summanwar (1993) reported that the population build-up of the pest was mainly related to the flushing rhythms of the plants. They also found maximum population on Mosambi sweet orange and citropsis (*Citropsis schweinfurthii*) in January and February, whereas the lowest population density occurred from July to October following monsoon rains. They also reported that life span of the psylla depends on the plant species on which it breeds. Similarly, Arora *et al.,* (1997) obtained a positive correlation between temperature and psyllid population and a negative correlation with relative humidity. Survivorship of adults of Asian citrus psyllid was best at humidity above 53 per cent, but there was significant survival at humidity as low as 7 per cent (McFarland and Hoy, 2001). Gupta and Bhatia (2000) found that the pest population was active throughout the year except for December and January. The peak activity of nymphs was observed during March-April (45-50/shoot) whereas, the adults assumed peak during April (20-23/shoot). Further, Kalita and Baruah (2001) reported that the population of *D. citri* reached its peak in the month of May and the correlation study showed that the population of psylla exhibited significant positive correlation with the minimum temperature. In Brazil, it has been observed that psyllids were present throughout the year but had a low population levels in the autumn and winter and the highest population density during the end of spring season and the beginning of summer season (Yamamoto *et al.,* 2001). Tsai *et al.,* (2002) observed the highest population density of *D. citri* (2.1 psyllids/shoot) on orange jasmine in September, 1999, but the highest population density (1.5 psyllids/shoot) on grapefruit was in early July, 1999. The mean population densities on orange jasmine and grapefruit were 0.49 and 0.45 per shoot, respectively from June, 1999 to July, 2000.Viraktamath and Bhumannavar (2002) recorded peak population of *D. citri* during March-April and July-August. In temperate regions, mild winter followed by favourable spring provided a suitable condition for high population build up. During winter, heavy mortality of pest *i.e.*, 53 per cent in July to 98 per cent in December occurred and the eggs fail to hatch, and 58 per cent of the hatched nymphs fail to develop into an adult. Survival studies conducted by Ashihara (2004) reported that the survival rates of 4-6 per cent of a population of *D. citri* in Kuchinotsu (northern Kyushu, Japan) following a winter with a minimum temperature of -3.3°C, but Mizuno *et al.,* (2004) observed 63 and 100 per cent mortality of adults of *D. citri* following 2 and 4 days of exposure to 0°C, respectively with no significant difference in mortality rates of males and females. Further, Shivankar and Rao (2005) observed that *Diaphorina citri* is more active in spring and after monsoon flushes but during winter and summer, however, thetemperature at 40°C was found detrimental to their population build up.

Moderate showers wash away the population. However, dry days witness rapid buildup of the pest. Heavy and prolonged flushing coupled with low temperature and high humidity favoured psylla outbreak. Nehru *et al.,* (2006) found that heavy rainfall during August had an adverse effect on the population of *D. citri* resulting in a sharp decline in population. Temperature and relative humidity ranging from 24.77 to 32.49°C and 40.85 to 65.78 per cent, respectively, proved conducive for the development of the psyllid and there was a positive and significant correlation (r=0.876) between psyllid count and temperature. These two biotic factors jointly influenced the population buildup of *D. citri* to the extent of 79.4 per cent. Similar work conducted by Hall *et al.,* (2008) recorded 26.5, 16.8 and 0.27 eggs, nymphs and adult/shoot, respectively on young grapefruit trees but on mature orange trees, 16.0, 12.7 and 0.31 eggs, nymphs, and adults/shoot were observed.

Population dynamics studies conducted by Sharma (2008) proved that the adult population of *D. citri* was very low during December and January but with the increase in temperature at the end of February, the activity of adults increased and the population of both adults and nymphs increased but significant increase in nymphal population was observed during March (41–47 nymphs). A decrease in nymphal population was recorded during May–June but attained the maximum infestation during July when the adult population was 92–111/25 leaves. It was also observed that the nymphal population also remained quite high during August, when the weather factors, *viz.* minimum, maximum, mean temperature (°C), relative humidity (%), the sunshine (hours) and rainfall (mm), respectively ranged from 26.0–27.2, 33.5–34.9, 30.4°C, 74–84 per cent, 6.3 to 9.3 hours and 24.5 to 297.7 mm. The correlations between population (mixed, nymphs and adults) of citrus psylla and different abiotic factors revealed that minimum, maximum and mean temperatures, relative humidity and vapour pressure had a positive relation with both nymphal and adult population whereas wind velocity had very low impact on adults. Further, Beattie and Barkley (2009) reported that *D. citri*is better adapted to regions with high saturation deficits (high temperatures and low relative humidity levels) than to regions with low saturation deficits (medium to high temperatures and high relative humidity levels). However, reduced oviposition by *D. citri* has been reported at relative humidity levels below 40 per cent (Skelley and Hoy 2004). Teck *et al.,* (2011) found that psyllid population levels are positively related to the availability of new shoot flushes. Psyllid populations are adversely affected by weather conditions and parasitoids. Adult psyllid populations increased exponentially during periods of flush growth and migration and dispersal of the adults was also related to flushing cycles.

Dispersal and colonisation of new trees are greatest in September-October, at the onset of the rainy season. Studies conducted by Rakhshani and Saeedifar (2013) reported that the nymph population peaks in three periods (beginning of March, end of August and end of January) and moderate climatic conditions coupled with the flushing of citrus tree are two main factors for an increase of the development and activity of nymphs resulting in pest population increase while, extreme of both high and low temp., low relative humidity and high rainfall were detrimental. Four coccinellids, one syrphid, two parasitoid and two spiders were intent as natural enemies of the psyllid. Devi and Sharma (2014) found that the population of *D. citri* was present throughout the year but only adults found surviving during December and February. There was no nymphal population when the maximum temperature was > 39°C or < 7°C. Two population peaks of nymphs were observed, first in April-May and second in August-September. Thereafter, there was abrupt decline in nymphal population during June and July during both the years when the weather conditions *i.e.,* maximum, minimum temperature (°C), relative humidity (%), rainfall (mm.) and the sunshine (hrs.) ranged from 24.4-44, 22.4-31.8, 25.5-100, 0-108.0 and 0-13.5, respectively. Highest peaks of an adult were found during May followed by June. With the decrease in temperature from the end of September, the population of *D. citri* started to decrease and reached its lowest during the winter season. Correlation analysis for both the years indicated that maximum and minimum temperature, sunshine and rainfall were positively correlated with nymphal, adult and mixed population but the effect of rainfall on adult population was non-significant, while relative humidity was negatively correlated. Population studies conducted by Sule and Muhamad (2014) reported a high number of adult *D. citri*in upper canopy, north cardinal point and leaves growth stage 1. The adult and immatures found on *C. suhuinensis* on all sampling dates, except in the months of December 2011 and January and May 2012, for immature. The peak population of *D. citri* adults were found in months of March and June in both years, while in immature peak populations were identified in the months of July 2011 and March 2012. Correlation analysis of *D. citri* adults and immature with flush growth leaves and weather parameters shows adult *D. citri* population to correlate with a number of flush leaves (r = 0.93) and temperature (r = 0.45), whereas, immature *D. citri* population only correlated with flush leaves. Jayanthimala *et al.,* (2015) study the role of biotic and abiotic factors in relation to citrus psylla incidence on mandarin (*Citrus reticulata*). The citrus psylla population was recorded high if minimum temperature ranged between 18.71-19.42°C, the maximum temperature ranged between 30.57-32.28°C and Max. Relative humidity is 87.1-95.6%. If minimum temperature ranged between 19.5-29.33°C with minimum relative humidity 64.6-81.0% then psylla population was high. The correlation analysis with weather parameters showed positive significant correlation with maximum temperature (r = 0.23) at$P$<.01 level and negative significant correlation with minimum temperature (r = -0.21) and rainfall (r = -0.18) at $P < 0.05$ level. Lakra *et al.,* (1983) demonstrated the key mortality factors for nymphs of *D. citri* as low relative humidity (<40%) during May-June and low temperature below 5°C during December-February. The most favourable conditions for population build-up were a gradual rise in daily minimum and maximum temperatures from late February to early May under dry conditions with relative humidity ranging from 30 to 75 per cent. Whereas Atwal *et al.,* (1970) observed that extremes of both high and low temperatures, however, were injurious to citrus psylla in Punjab. Exposure to -3°C for 1 hour was lethal for nymphs and exposure to -10°C was lethal for adults (Xu *et al.,* 1994). Working on population Wankhade *et al.,* (2015) observed that the peak nymphal population of citrus psylla in the month of February-March and August-September and it was low in May-June and December. The reduction in the pest coincided with a reduction in new flushes during April to June months and decreased with a low temperature in November and December months and increased in temperature from May to June month.

Biology of citrus psylla

Many workers studied the biology of *D. citri* in India (Hussain and Nath, 1927; Pruthi and Mani, 1945; Mangat, 1966; Atwal, 1962 and Singh, 1963) and Philippines (Catling, 1970). Working on nymphal instars, Hussain and Nath (1927) gave a detailed description of all the five nymphal instars. The nymphs are orange yellow, flattened and circular in shape. They remain congregated close to the site of oviposition and for few days feed there. Subsequently, they move to older parts like matured leaves, thick shoot, petioles etc. The nymph cast skin five times (Atwal, 1962) and become adult in 12 to 25 days (Pruthi, 1969) or 8-60 days (Viraktamath and Bhumannavar, 2002). Morphological studies conducted by Bindra (1969) observed almond-shaped yellow eggs laid during day time either singly or in clusters or in groups of double and triple straight lines deep into the tender plant tissue with the help of strongly pointed ovipositor and were anchored there by means of a short stalk embedded in the plant tissue. Pande (1971) Studied the biology of *Diaphorina citri*, Pairing started soon after emergence. Fecundity was 180-520 eggs/female. The incubation period lasted for 4-18 days. There were five nymphal instars, which took 10-30 days. The adults were long-lived. The complete life-cycle took 14-48 days. Ten overlapping generations were detailed in a year. The insect was most active during March-April**.** Aubert and Quilici (1988) reported a sex ratio of 49 per cent males to 51 per cent females. Females continuously lay eggs throughout their lives if young leaves are present. Adult females have been observed during their lifetime to lay 500 to 800 or more eggs over a period of two months with a maximum of 1900 (Nava *et al.,* 2007). Dharajothi *et al.,* (1989) studied the spatial distribution of *D. citri* in the greenhouse and in the field eggs and nymphs follow a contagious distribution, whereas the adults show random to aggregated distribution. The mean population density of different stages of the insect among the four directions (north, east, south and west) of a tree canopy does not vary significantly. Khan *et al.,* (1989) studied the biology of the citrus aphalarid, *D. citri* on an alternative food plant in the laboratory; adults reached sexual maturity 2-6 days after emergence. Oviposition took place (singly or in clusters on all the tender parts of the plant) immediately after mating up to 350 eggs were laid by a female in 14 days. The egg stage lasted 2-11 days and the nymphal stage (5 instars) 12-x22 days. Adults lived for 14 days and there were 9 overlapping generations in a year. Similarly, Chavan and Summanwar (1993) observed that females laid eggs in feather flush. The eggs measure 0.3 mm in length and 0.13 mm in width with 0.038 mm long stalk (Hussain and Nath 1927). Around Ludhiana, eggs hatch in 3-4 days (April-October), 5-6 days (November and March), 7 days (February) and 11-12 days (December-January) (Mangat, 1966) depending on the time of the year. Just before hatching red coloured eyespots become visible through the eggshell. The nymphs took 6 to 9 minutes to emerge from the egg.

Working in China, Xu *et al.,* (1994) reared *D. citri* on caged citrus and *Murraya paniculata* plants. They found that it completed 6-7 generations on citrus and 9-11 generations on

M. paniculata annually in the Fuzhou area in Fujian, China. Average adult lifespan was 30-40 days and each generation lasted 18-59 days in spring and autumn. Overwintering adults had a lifespan of 260 days. In India, Chakravarthi *et al.,* (1998) studied the biology of *Diaphorina citri* on three different hosts *viz.* acid lime, sathgudi, sweet orange and curry leaf. Among the three-host curry leaf was the most preferable host with a high rate of fecundity and short duration of the life cycle. Liu and Tsai (2000) reported the low-temperature developmental thresholds for 1st through 5th instars were estimated at 11.7ºC, 10.7ºC, 10.1ºC, 10.5ºC and 10.9ºC, respectively. The mean longevity of females increased with decreasing temperature within 15-30ºC. The maximal longevity of individual females was recorded 117, 60, 56, 52 and 51 days at 15ºC, 20ºC, 25ºC, 28ºC and 30ºC, respectively. The average number of eggs produced per female significantly increased with increasing temperature and reached a maximum of 748.3 eggs at 28ºC. The population reared at 28ºC had the highest intrinsic rate (0.199) and net reproductive rate (292.2), and the shortest population doubling time (3.5 days) and mean generation time (28.6 days) compared with populations. Further, Tsai and Lui (2000) reported that survival of immature on orange jasmine, grapefruit, rough lemon and sour orange was 75.4, 84.6, 78.3 and 68.6 per cent, respectively. Female adults lived for 39.7, 39.7, 47.6 and 43.7 days respectively, on these host plants. The average number of eggs laid per female on grapefruit (858 eggs) was significantly more than those on other hosts. The mean population generation time on these hosts ranged from 31.6 to 34.1 days. Skelley and Hoy (2004) studied that adult of *D. citri* ceased laying eggs when rearing temperatures reached 34°C for five days; once temperatures were reduced, the adults gradually began laying eggs again over 2-3 weeks. Psyllid produced fewer eggs when relative humidity dropped below 40 per cent. Adults may live several months and the females lay as many as 800 eggs in a lifetime (Mead, 1997). Nakata (2006) reported that nymphs of citrus psylla fail to develop to adults at 15.0°C and the mortality increased at 32.5°C. The incubation period decreased at a higher temperature, varying from 15.0 to 2.5 days. These nymphs became adults in 36.3 days at 15.0°C and in 10.7 days at 30^{0} C, but 16.8 days at 32.5^{0} C. Nehru *et al.,* (2006) found that the incubation period of eggs of *D. citri* on *Citrus sinensis* cv. Jaffa ranged from 3.01-8.49 days during different generations. It passed through 5 nymphal instars. The total nymphal period varied from 9.14 to 25.05 days. The pre-copulation, pre-oviposition and oviposition periods varied from 2.09 to 7.26, 1.38 to 3.90 and 10.00 to 38.38 days, respectively. The respective adult longevity in male and female ranged from 10.41 to 74.00 and 13.77 to 80.22 days.

Fung and Chen (2006) were used to generalise developmental times from egg to adult at different temperatures. New adults reach reproductive maturity within 2 or 3 days, and oviposition begins about 1 or 2 days after mating (Wenninger and Hall, 2007). The mean population generation time at 25°C was, therefore, ranged from 20-22 days. Chhetry *et al.,* (2012) observed that there were five nymphal stages with length varying from 0.26 -2.96 mm. The incubation, nymphal and adult longevity were 2.28 ± 0.18, 14.86 ± 1.07 and 10 ± 1.23 days, respectively. Thus, the psyllid has a total life cycle of 20-36.5 days (27.14 ± 2.34 days) in laboratory conditions. Devi and Sharma (2013) reported that the number of eggs laid per female on kinnow (683± 86.11) and rough lemon (672 ± 83.47) was significantly more than on curry leaf (616 ± 65.85) and incubation periods varied from 3-4 day and no significant difference of nymphal development periods on all host plant. The average female longevity on a rough lemon

(43 days) was significantly higher than kinnow (42.2 days) and curry leaf (39.7 days). There could be 6-16 generations in a year depending on prevailing weather conditions. *Diaphorina citri* is known to infest host plants other than citrus like curry leaf (*M. koenigii*) and it is the most preferred host with high rate of fecundity and short duration of life cycle. The pest completes 9-10 or even upto 16 overlapping generations in a year (Hussain and Nath 1927 and Khan *et al.,* 1989).

Chemical control

Several insecticides like monocrotophos, dimethoate, aldicarb, quinalphos, fenvalerate, fenthion, phosalone, oxydemeton methyl, diazinon, phosphamidon, malathion, fenitrothion, acephate, carbaryl and endosulfan were found quite effective against psylla (Radke *et al.,* 1981; Buitendag, 1988; Tandon, 1992).The systemic neonicotinoid insecticide Imidacloprid (Admire), was applied to grapefruit, *Citrus paradisi* trees to determine its effects in the control of Asian citrus psyllid, *D. citri*. Significant positive correlations were obtained between imidacloprid titers in leaf tissue and the percentage of control levels achieved (Setamou *et al.,* 2010). Dahiya *et al.,* (1994) proved that insecticides like dimethoate (0.05%), monocrotophos (0.05%), phosphamidon (0.05%), decamethrin (0.002%) and fenvalerate (0.006%) gave better control of citrus psylla cypermethrin (0.006%), chlorpyriphos (0.05%), dichlorvos (0.05%), endosulfan (0.05%), malathion (0.05%) and quinalphos (0.05%). Ahmed *et al.,* (2004) at Sarghoda, Pakistan found that methamidophos (500 ml/ acre), dimethoate (300 ml/ acre) and imidacloprid (250 g /acre) had almost equal effect on the population reduction of *D. citri* infesting Feuterell's early, Kinnow and musambi. All insecticides resulted in 90% reduction up to 7 days after spraying. Arora *et al.,* (2005) reported that a pooled analysis over three years data revealed that two days after application, quinalphos (0.075%) gave highest reduction 96.58%in nymphal population of citrus psylla. This was comparable to imidacloprid (0.08%) treatment recording 95.12% nymphal mortality. Seven days post application, imidacloprid (0.08%) was found to be superior followed by quinalphos (0.075 and 0.05%). Parallel results were obtained ten days after spraying also. The most effective treatment was imidacloprid (0.08%) causing 95.33% reduction in nymphal population, but it was at par with quinalphos (0.075%), quinalphos (0.05%) and triazophos (0.075%). Data reveled that quinalphos (0.05%) was most effective treatment for the control of citrus psylla. Further, Childers and Rogers (2005) revealed that treatment of systemic insecticide, imidacloprid had significantly lower adult population 5 DAT while aldicarb did not. However, both systemic insecticides provided the longest residual control of nymphs after 19 DAT. The insecticides spinosad and acetamiprid were ineffective in reducing adult population. The insecticides thiamethoxam, fenpropathrin and chlorpyriphos provided a significant reduction in adults. Dadmal *et al.,* (2002) at Akola, Maharashtra tested different plant products & chemical insecticides and found that acephate @ 0.05% was the most effective against *D. citri*. It controlled 97.59 and 98.95% nymphs of citrus psylla at 3 and 7 days after spraying (DAS), while azadirachtin (1500 ppm) gave 78.53% and 82.92% nymphal mortality at 3 and 7 DAS. Farmanullah *et al.,* (2005) observed that the overall mean population was lowest 3.63 and 2.65 adults per six inches tender shoots in thiamethoxam 25WG treated plants after 1st and 2nd application, respectively, however, per cent decrease of psylla population in comparison to control after the first and second spray was also highest (72.20 and 83.54) in thiamethoxam 25WG as compared to other insecticides.

Powell *et al.,* (2007) evaluated the number of psyllids, per cent trees infested and the percentage of flush infested per tree was recorded over a 3-yearperiod. The plot was treated with 7 insect control treatments: Admire (imidacloprid) applied at12, 6, 3, or 2-month intervals; Temik and Meta-systox R applied annually, orinsecticide control using a randomised complete block design. Annual applications of Temik, Meta-Systox R, or Admire did not reduce psyllid populations. Biannual or more frequent applications of Admire significantly reduced psyllid numbers, the percentage of trees with psyllid infestations, and the percentage of flushes infested with psyllids. The data on bioefficacy of different insecticides indicated that except dimethoate (0.05%) with 69.7 per cent nymphal mortality after 12 days of spray all other insecticides namely dimethoate (0.075%), oxy demeton methyl (0.075%), imidacloprid (0.008%), chlorpyriphos (0.1%), triazophos (0.1%), thiamethoxam (0.008%) and quinalphos (0.075%) had significantly high (91-100%) nymphal reduction of *D. citri* compared to either 3 or 7 days data (Sharma, 2008). Boina *et al.,* (2009) concluded that feeding by psylla adults and nymphs on citrus plants treated daily with a sublethal concentration (0.1microgm/L) of imidacloprid significantly decreased (8 days), fecundity (33%) and fertility (6%) as well as nymph survival (12%) developmental rate compared with untreated controls. The magnitude of these negative effects was directly related to exposure duration and concentration. Furthermore, psylla adults that fed on citrus leaves treated systemically with lethal and sublethal concentrations of imidacloprid excreted significantly less honeydew compared with controls in a concentration-dependent manner suggesting the antifeedant activity of imidacloprid. The effect of seven insecticides from different groups *viz.* dimethoate, acetamiprid, flufenoxuron, fuzalon + teflubenzuron, thiamethoxam, pyriproxyfen and oil showed that all tested insecticides had a good effect on the pest during spraying time gradually the effect of contact insecticides decreased as such their effect compared to become significant. In this study thiamethoxam, dimethoate and acetamiprid showed the maximumper cent of mortality (97.7, 83.2 and 82.7%, respectively). The least per cent of mortality (18.7%) was obtained by using the oil, 21d after treatment (Abbaszadeh *et al.,* 2011). Arora and Sharma (2011) studied the bio-efficacy of some neonicotinoids, *viz.*, acetamiprid, imidacloprid and thiamethoxam @ 0.004, 0.006, 0.008 and 0.01% against citrus psylla, *D. citri* was evaluated. The results indicated that up to 7 days after spraying, imidacloprid (0.01%)showed the highest reduction in the nymphal population of citrus psylla but it was found to best statistically on par with thiamethoxam @ 0.01% and thiamethoxam @ 0.008%. Ten days after spraying thiamethoxam @ 0.01 and 0.008 per cent was found equally effective against citrus psylla. It is concluded that imidacloprid was very effective for initial knockdown of citrus psylla upto seven days after treatment whereas thiamethoxam had a greater residual effect as compared to imidacloprid and acetamiprid. Acetamiprid was found to be less effective compared to thiamethoxam and imidacloprid. Rao and Shivankar (2011) reported the toxicity of bio-rational insecticides *viz.* spinosad, abamectin, novaluron, sweet flag (*Acorus calamus* L.), petroleum spray oil, neem (*Azadirachta indica)* oil, azadirachtin, *Bacillus thuringiensis*, *Verticillium lecanii* and dimethoate (as standard) against the second instar nymphs of citrus psylla 2006. Based on LC50 values, spinosad, abamectin and novaluron were 9.93, 3.29 and 2.71 times more toxic to psylla nymphs than dimethoate. Further, field appraisal of these bio-rational insecticides along with neem soap and Pongamia (*Pongamia glabra* Vent.) soap against citrus psylla in 10-year-old acid lime (*Citrus aurantifolia*) cv. Pramalini showed that abamectin @ 0.38ml/L (90.2-92.5% reduction) followed by petroleum spray oil @ 5.9 ml/l (89.8-90.4%reduction) novaluron @ 0.55 ml/l (87.6-88.1% reduction) and spinosad @ 0.15 ml/l(65.5-72.3% reduction) were found effective against citrus psylla for a period of 15 days.

Sarada *et al.,* (2014) reported that the treatments were imposed during peak pest infestation period (December-March). All the treatments recorded low ACP population then control irrespective of the year and days after treatment. However, during both the years, novaluron10EC (0.005%) recorded highest (80%) pest control at 7DAS. This was on par with azadirachtin (1%) and dimethoate30EC (0.06%, standard check). At 14DAS also the same chemicals have shown superior performance with >70% pest control. The effectiveness of the insecticides was in the order of novaluron> azadirachtin> dimethoate> *Verticillium lecanii*> neem oil> abamectin. Dalvaniya *et al.,* (2015) reported that among the treatments, imidacloprid 17.8 SL @ 3.0 ml/10 liters water was most effective with minimum population of *D. citri*at 1, 3, 7 and 10 days after spray, followed by diafenthiuron 50 EC @ 4.0 ml/10 litres water and thiamethoxam 25 WDG @ 3.20 g/10 liters water. Quasim and Hussain (2015) revealed that the efficacy of insecticides against citrus psylla, and mortality was observed after three days, seven days and then after one month. Four insecticides, Polytrin-C, Talstar, bifenthrin and imidacloprid applied, had an almost equal effect on the population reduction of citrus psylla on all citrus plants. Three days of spray showed a control of 96.91%, 94.33%, 93.83% and 93.06% following insecticides Polytrin C, imidacloprid, bifenthrin and Actara, respectively, calculated by Minitab 15. Psylla adults were exposed to different concentrations (500, 400, 300, 200 and 100 ppm) imidacloprid and bifenthrin, and two controlled conditions (with leaves and without leaves). Both imidacloprid and bifenthrin insecticides proved to be the most effective against *D. citri* with lethal times (LT_{50}) of 4 and 5 hours, respectively, at a concentration of 500 ppm, calculated from probability test with Minitab-15. Wankhade *et al.,* (2015) evaluated against citrus psylla, the treatment with abamectin 1.9 EC @ 0.4 ml/l (0.0007%) was found most effective in recording the least nymphal population of citrus psylla at 3rd, 7th and 14th days after sprays over rest of the treatments. The next best treatment was imidacloprid 17.8 SL @ 0.25 ml/l (0.004%). Dimethoate (0.06%) recorded 18.18, 13.94 and 9.35population of citrus psylla nymphs at 3rd, 7th and 14th days after sprays, whereas, bio-rationals *i.e., V. lecanii* and *B. bassiana* recorded 33.97, 22.13, 17.97 and 39.00, 33.18, 28.32 respectively at 3rd, 7th and 14th days after sprays.

Biological control of citrus psylla

Biological control should be encouraging where the insects are beyond the reach of chemical control. Therefore, the extent of their impact in Haryana requires further investigation. In addition to parasitism and host feeding by citrus psyllid parasitoids, the primary sources of psylla mortality in the field are naturally occurring generalist predators such as ladybird beetles, syrphid flies lacewings, and predatory mites (Michaud and Olsen, 2004; Michaud, 2004; Qureshi and Stansly, 2009; Juan-Blasco *et al.,* 2012; Kistner *et al.,* 2016). Yang *et al.,* (2006) reported that *D. citri*in China was attacked by lacewings, *Chrysopa boninensis* Okamoto and *Coccinella septempunctata* Linnaeus, praying mantids, the whirligig mite and ants. Ants probably predate on immature *D. citri* in Florida (Michaud, 2002). *Diaphorina citri* has been found to be attacked by Coccinellids in

Brazil (Gravena *et al.,* 1996), syrphid flies in the genus *Allograpta* in Reunion and Nepal (Aubert 1987), and (Allograpta oblique Say) in Florida (Michaud 2002). In India, lady beetles like *C. septempunctata*, *C. rependa*, *Cheilomenes sexmaculata*, *Chilocorus nigrita* and *Brumus suturalis* (Fabricius) attacked *D. citri* (Husain and Nath 1927 and Batra *et al.*, 1990). Van den Berg *et al.,* (1992) reported eighteen species of spiders preying on *T. erytreae,* predominantly belonging to family Salticidae but the most abundant spider was *H. velox*, a species known to develop successfully on nymphs of citrus psylla. In region of Jammu, Bhagat and Nehru (1999) observed the Lady bird beetle, *Coelophora saugeti* and green lacewing, *Chrysoperla carnea* potential natural enemies of citrus psylla. And Gupta and Bhatia (2000) reported that four species of predatory coccinellids, viz. *Leis dimidiate* (Fabricius), *M. sexmaculatus*, *Micraspis cardoni* Timberlake and *C. septempunctata*, and a chrysopid predator were observed feeding on nymphs during the spring season. Singh (2017) observed that the two predatory beetles namely *Coocinella Septempunctat* (Linneaus) and *cheilomenes sexmaculata* (Febricus) in sweet orange field in agro climatic condition of Haryana.

The extent of control provided by each individual taxa remains largely unknown, though coccinellids seem to provide the citrus psylla control in Florida (Michaud, 2004; Qureshi and Stansly, 2007), a situation not seen in southern California. Work from Pakistan strongly suggests spiders are not important predators in unsprayed citrus orchards (Vetter *et al.,* 2013). *Tamarixia radiata*, an ectoparasitoid, is a native to India (Chien, 1995) and plays an important role in biological control of *D. citri* than predators (Husain and Nath, 1927). Female of *T. radiata* attacks *D. citri* during 3rd, 4th or 5th instar of nymphal development (McFarland and Hoy, 2001 and Skelley and Hoy 2004). *Tamarixia radiata* is a host-specific, ectoparasitoid of *Diaphorina citri* nymphs, originally described from specimens that emerged from parasitized nymphs on lemon leaves collected from Pakistan (Waterston, 1922). In Taiwan, *T. radiata* had higher population than *D. aligarphensis* during parts of the years (Cheu *et al.,* 1987). In China (Yang *et al.,* 2006) reported that 36 per cent parasitism rate was observed on new branches in the summer, and 46 per cent on branches in the autumn and negative relationship between the parasitism rate (per cent between parasitized and total nymphs) and the percentage of branches with *D. citri* nymphs, but there was no relationship between the nymphal parasitism rate and the percentage of branches infested with adult (Paiva and Parra, 2012).

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