Chapter

Ecology, Biology, Damage, and Management of Sucking and Chewing Insect Pests of Citrus

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Abstract

Citrus are important commodities for human and animal nutrition but these crops are attacked by a plethora of dangerous agents, including viruses, bacteria, fungi, and invertebrates that decrease the yield significantly. Within invertebrates, insects are the more prevalent citrus pests causing plant damage or act as diseases vector. In this chapter, we focused in the insect pests with worldwide distribution in citrus orchards, including sap sucking Asian citrus psyllid *Diaphorina citri*, citrus mealybug *Planococcus citri,* citrus whitefly *Dialeurodes citri*, thrips representatives such as *Scirtothrips citri* and *Pezothrips kellyanus*, and chewing citrus leafminer *Phyllocnistis citrella* and lemon butterfly *Papilio demoleus*. These pests are distributed across various regions of different continents such as in Asia-pacific, Americas, Africa, and Oceana. We presented detailed data from these pests' biology, ecology, damage, and methods for control. The pest incidence and biology is affected by various biotic and abiotic factors thus providing the opportunity to use these factors as method of intervention to disturb pest life cycle. In this context, several IPM techniques such as cultural, physical, biological, and chemical methods were elaborated, which could help to reduce the pest status below damaging levels.

Keywords: citrus, sooty mold, Asian citrus psyllid, citrus greening, citrus mealybug, citrus leafminer, citrus canker, biological control, pest management

1. Introduction

Citrus is one of the largest grown fruit crops in various tropical and subtropical regions of the world, including Brazil, China, USA, India, Pakistan, Italy, Spain, Australia, and Argentina. The genus *Citrus* includes various species of oranges, mandarins, grapefruits, limes, and lemons, which belong to Rutaceae [1, 2]. The production of citrus is limited by biotic (insect pests and pathogens) and abiotic factors (temperature, humidity, soil conditions, and availability of water). Within biotic factors, insects are major constraints in the optimum production of citrus [3–5]. About 250 species have been reported to cause damage to citrus plants but only few pests become a regular problem and cause heavy damage [6]. Overall, the yield losses due to activity of citrus insect pests may reach to 50% without timely diagnosis and management. Citrus insect pests are categorized into sucking and chewing. The eco-biology, damage pattern, and management strategies for each of these citrus pests are discussed in detail in this chapter (summary of citrus insect pests is also given in **Table 1**). Proper pest identification and understanding the eco-biology and damage patterns of citrus insect pests can help to devise and implement suitable pest management program, which can be cost-effective and environmentally friendly and ultimately help to enhance the yield potential of citrus crop.

2. Sucking insects

These insects deprive the citrus plants from essential nutrients by feeding on sap of tender plant parts such as leaves, fruit buds and green stems, and branches using piercing-sucking or rasping-sucking mouthparts. Detail of important sucking insect pests of citrus is given below:

2.1 Asian citrus psyllid

It is also known as citrus psylla. The biological name of this insect is *Diaphorina citri* Kuwayama. It belongs to order Hemiptera and family Liviidae.

2.1.1 Distribution

Diaphorina citri is a serious insect pest of citrus groves in different regions of the world. It was first reported in Taiwan [14] from where it invaded to many citrus-growing regions of the world, including Brazil [15], India [16, 17], Pakistan [18], Southern California [19], Texas [20], Florida [21], Australia [22], Colombia [23], Caribbean [24], Mexico [25], Indonesia [26], Iran [27], Kenya [28], Japan [29], Oman [30], Ethiopia [31], Malaysia [32], and Bangladesh [33].

2.1.2 Eco-biology

Diaphorina citri is mainly a pest of tropical and subtropical climate. New foliage growth (flush) regulates the dynamics of *D. citri* requiring soft tissues for oviposition and development [34]. The peak period of psyllid is coinciding with new flush and pest becomes active at the end of February (late winter) and population reaches at maximum level in March and April (spring season). The adults become active in May (early summer) and June and new colonies develop in July (mid-summer). The population begins to decline in October (autumn) and only fraction of population is observed at the end of December and January (winter season) [35]. Reproduction of *D. citri* is totally dependent on availability of young shoots containing feather stage to recently expanded tender leaves. Adult females feed on tender shoots to mature their eggs and prefer opening buds and emerging shoots for oviposition. During the following 2–3 weeks, shoot and leaf tissues are still tender and are utilized by nymphs and adults to complete development and mature eggs, respectively [34, 36]. Adults can also feed and survive on the fully developed leaves for several months. Temperatures between 24°C and 30°C are most favorable for both adult survival and reproduction, as adults survive for 30–50 days and females lay about 500–800 eggs at these temperatures [37, 38]. The damage caused by *D. citri* is most severe in autumn than in

Common name	Species name	Family	Mode of feeding	ETL*
Asian citrus Psyllid	*Diaphorina citri*	Liviidae	Piercing-sucking	(i) 0.5–1.0 adult psyllid per stem tap [7] or (ii) 6 nymphs or adults per leaf [8]
Whitefly	*Dialeurodes citri*	Aleyrodidae	Piercing-sucking	20–30 nymphs per leaf on oranges and lemons and 5–10 nymphs per leaf on mandarin species [9]
Mealybug	*Planococcus citri*	Pseudococcidae	Piercing-sucking	(i) 5–10% fruit infestation by colonies of young nymphs in summer and (ii) 15% fruit infestation in autumn [10]
Thrips spps.	*Scirtothrips citri* *S. aurantii* *S. dorsalis* *S. inermis* *Pezothrips kellyanus* *Megalurothrips kellyanus* *Thrips major*	Thripidae	Rasping-sucking	10 thrips/branch tapping [11]
Red scale	*Aonidiella aurantii*	Diaspididae	Piercing-sucking	3–5 nymphs per leaf [12]
Blackfly	*Aleurocanthus woglumi*	Aleyrodidae	Piercing-sucking	5–10 nymphs per leaf [13]
Leafminer	*Phyllocnistis citrella*	Gracillariidae	Larvae burrows beneath the leaf epidermis and consume the leaf tissues by feeding in serpentine manner	10% infestation [8]
Lemon butterfly	*Papilio demoleus*	Papilionidae	Larvae feed upon both young and mature leaves and cause defoliation	3–5 larvae per plant [13]
Fruit fly species	*Bactrocera zonata* *Ceratiitis capitata* *B. tryoni*	Tephritidae	Larvae burrow inside the fruit and consume the fruit pulp	20 adults per trap per week [12]

**Economic Threshold Level.*

Table 1.
Summary of citrus insect pests.

summer. The order of severity varies due to type of host plant, age, abundance of flush, variation in flush phenology, and management practices [39].

D. citri has three developmental stages of life, for example, egg, nymph, and adult. Bindra [40] observed almond-shaped eggs that are yellow in color and are laid during day time either isolated or in masses of double or triple lines embedded into leaf tissue with short stalk. *D. citri* has five nymphal instars that are orange to yellow in color, with rounded flattened body (**Figure 1**) [35]. Pande [41] studied the biology of *D. citri*, finding that mating onset just after adult emergence.

The egg laying capacity per female is about 180–520. The incubation period ranges from 4 to 18 days according to environmental conditions. Nymphs have five instars, which take 10–30 days to adult molt. The adults survive longer and take 14–48 days to complete their life cycle. *D. citri* has 10 overlapping generations per year [41].

2.1.3 Damage

Diaphorina citri is one of the devastating sucking insect pests of citrus plantations and losses due to attack of this pest ranges from 82 to 95% [42]. Both the nymphal and adult stages of this pest feed on juvenile plant shoots and leaves and floral buds and deprive the plant from essential nutrients by sucking phloem sap. Its infestation results in leaf curling, distortion, and shedding of flower and leaves [43, 44]. They also inject toxic saliva in the citrus plants during feeding [43]. The host range of *D. citri* has been known to be *Citrus* spp. and near relatives, spanning over 23 genera within the Rutaceae [45]. During its feeding, *D. citri* (4th and 5th instars and adults) transmits gram negative and phloem-limited bacterial pathogens (*Candidatus* Liberibacter *asiaticus*, *Candidatus* Liberibacter *americanus*, and *Candidatus* Liberibacter *africanus*) to citrus plants. These pathogens are the causal agents of devastating disease in the citrus plantations, which is known as citrus greening or Huanglongbing (HLB) or yellow dragon disease [46, 47]. The citrus greening is one of world's most serious diseases of all citrus cultivars. This disease is a threat for citrus industry throughout the world as it has perished millions of hectare of citrus in about 40 countries [48]. This disease results in poor quality fruit production, severe yield

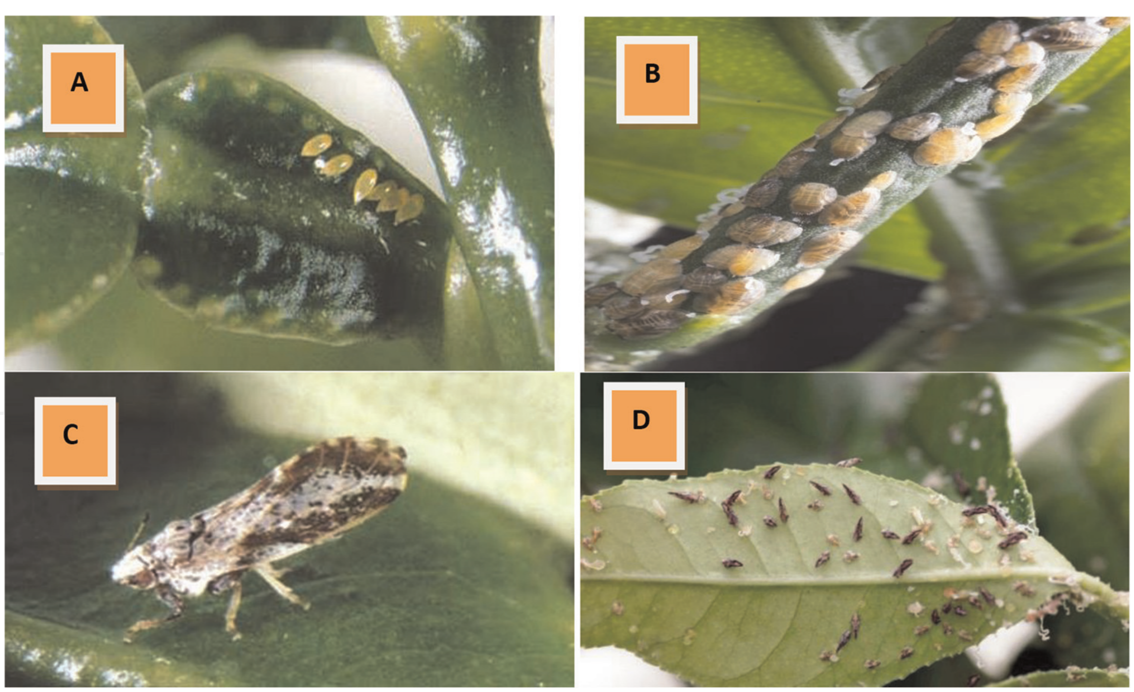

Figure 1.
Scaly eggs of Diaphorina citri *laid singly in a row below the leaf surface (A), nymphal instars of* D. citri *congregated for feeding at soft branch (B), adult* D. citri *with elaborated body features and sitting in upright position with rear raised (C), and adults of* D. citri *infesting the underside of leaf surface and secreting honeydew and wax (D). Photographs by Douglas L. Caldwell, University of Florida, USA (A and C), https://www.koppert.com/challenges/pest-control/psyllids/asian-citrus-psyllid/ (B) and the citrus pest and disease prevention program, California Department of Food and Agriculture, USA (D).*

reduction (30–100%), and ultimately death of whole plant within 5–8 years of attack [49–51]. Other symptoms of HLB infection are progressive blotchy mottling of leaves, plant stunting, off-season bloom, deformed, small-sized, and off-flavor fruit with high acid contents and bitter taste and premature fruit drop thus inducing market losses in fresh and processed fruits [52–54]. Asymmetrical patterns with yellow veins on leaves are also clear indication of citrus greening. In addition to these, several other symptoms such as stunted plant growth, shoot dieback, fruit drop, and overall yellow appearance of citrus plants are visible signs of HLB infection [55]. Before the appearance of visible symptoms, the initiation of root dieback and decrease in root-shoot ratio have also been observed in HLB-infected plants [56].

2.1.4 Management

2.1.4.1 Biological control

Biological control is the control of insect pests using predators and parasitoids and should be adapted at large scale to avoid the unnecessary use of insecticides. There are various predators and parasitoids of *D. citri* in the citrus crop. The primarily source of generalist predators are syrphid flies, ladybird beetles, lacewings, predatory mites, and ants [57]. The immature of *D. citri* are attacked by ants [58]. Husain and Nath [35] and Batra et al. [59] also reported that different species of coccinellid attack the *D. citri* such as the seven-spot ladybird beetle *Coccinella septempunctata* Linnaeus, transverse ladybird beetle *C. repanda* Thunberg, Malaysian ladybird beetle *Chilocorus nigrita* (Fabricius), zigzag ladybird beetle *Cheilomenes sexmaculata* (Fabricius), and three-striped lady-beetle *Brumus suturalis* Fabricius. The larvae of syrphid fly *Allograpta* spp. have been reported to attack *D. citri* nymphs in the regions of Nepal and Reunion [60]. The primary effective parasitoids of *D. citri* are *Tamarixia radiata* (Waterston) (Hymenoptera: Eulophidae) [61] and *Diaphorencyrtus aligarhensis* (Shafee, Alam and Argarwal) (Hymenoptera: Encyrtidae) [62], which are native to India and provide better control than predators. Female of *T. radiata* prefers the 3rd, 4th, and 5th nymphal instars of *D. citri* [63, 64].

2.1.4.2 Chemical control

There is significant increase in insecticide use per year to control *D. citri* and citrus greening and annual cost for managing this pest could range from $US 240 to>$US 1000 depending upon application frequency, type of insecticide sprayed, and method of application [65]. Among various types of insecticides, the foliar applied broad-spectrum insecticides are recommended to control the *D. citri* prior to flushing (to kill the overwintering adults) and during growing season. Foliar sprays with broad-spectrum insecticides such as chlorpyrifos, dimethoate, fenpropathrin, bifenthrin, and zeta-cypermethrin along with foliar and soil applications with systemic neonicotinoid insecticides such as imidacloprid, thiamethoxam, and clothianidin are indicated to control *D. citri* [66–68]. Imidacloprid offers 50–90% control of adult psyllid population in the field (reviewed by Boina and Bloomquist, [48]). Spray of imidacloprid in rotation with chlorpyrifos or cypermethrin at two-week interval also reduces the psyllid population and incidence and spread of HLB during new flush stage of citrus plants [69]. In the world, all citrus-growing areas are not free from attack of citrus greening and its vector. There is no permanent cure for controlling this pest except chemical control, which keeps the pest population at low level and is one of most effective management options for controlling the pest incidence and spread of citrus greening disease.

2.1.4.3 Miscellaneous tactics

Chemical and biological control should be combined with other control measures such as promoting a clean cultivation, which includes using a disease free and transgenic plants that are resistant to *D. citri* and removal of infected plants from the field; and use of antibiotics (e.g., tetracycline hydrochloride) for suppression of citrus greening symptoms is viable and sustainable tool to control the incidence of HLB [70]. To reduce the insecticides resistance in the *D. citri*, there is an immediate need for development of IRM (insecticide resistance management) strategies. Regular monitoring of *D. citri* in field to determine the rate of development of insecticide resistance is one of the major components of IRM. In addition, resistant colony should be developed in the laboratory for determining the genetic nature, mode of inheritance, stability of resistance, fitness costs, and pattern of cross resistance in order to manage insecticide resistance.

2.2 Citrus whitefly

Citrus whitefly (CWF) belonging to order Hemiptera and family Aleyrodidae is technically known as *Dialeurodes citri* (Ashmead).

2.2.1 Distribution

Dialeurodes citri has a wide range of distribution in different regions around the world [71]. With its origin in Southeast Asia, CWF occurrence was reported from southeastern United States mainly in Florida in the 1880s [72] from where in 1900 it spread to California, a region in the western United States [73]. Later its occurrence was recorded in the Mediterranean countries such as Western Galilee region of Israel in 1975 [74, 75] and in the Turkey's Eastern Mediterranean citrus groves in 1976 [76, 77]. In 1977, invasion of this species in citrus orchards was reported from South Adriatic, near Dubrovnik [78]. This species has also been detected from Oceania, New Zealand, in 2000 [79]. In Asia, this species is infesting citrus orchards in several parts of Pakistan [80], Taiwan, Japan, and China [81, 82], Uzbekistan, and Turkmenistan [83], and India [84, 85].

2.2.2 Eco-biology

The eggs of CWF are yellow and have smooth surface. Female adults lay their eggs on leaves and 8–24 days are required for hatching according to climate [86]. The CWF is an arrhenotokous species [87] in which unfertilized eggs always develop into males. The nymphs are elliptical, flat, and scale like. After first molt, the instars become fixed (legs and antennae are lacking) at the underside of the leaf surface until the adult stage. About 23–30 days are required to complete the nymphal period. The pupa of CWF is opaque and eye spots of developing adult are clearly visible from pupal integument and pupa completes its development in about 13–30 days. The total life cycle from egg to adult formation is completed in 41–333 days according to the ecological conditions such as temperature, humidity, and rainfall. The CWF overwinters as nymph (fourth instar) at the underside of the leaves. The pupae appear early in spring and in March-April (late spring) the adult emergence occurs [86]. The number of generations varies according to the region with 2–5 per year [75, 88].

2.2.3 Damage

The CWF has sucking mouth parts and both nymphs and adults injure the plants by sucking sap. The further injury is caused by honeydew release, which results in the development of sooty mold fungus over fruits and foliage [86]. The sooty mold may cover the leaves and cause indirect damage by interfering with respiration and photosynthetic activity of plants, which leads to leaf drop and yield reduction [75]. The infested citrus trees become weak and tasteless. Easy peeler citrus varieties such as mandarins and sweet orange cultivars are preferred citrus hosts of CWF [87]. Besides this, CWF has also been reported as a vector of disease known as Citrus Yellow Vein Clearing Virus (CYVCV) [89]. This viral disease was reported for the first time from Pakistan in 1988 in sour orange (*Citrus aurantium* L.) and lemon (*C. limon* Burm.f.) [90]. Now this disease is widely distributed in major Chinese province of citrus-growing areas and considered to be most serious disease, which affects the lemon production [91]. The major symptoms of CYVCV that appear in sour orange and lemon are severe vein clearing, vein necrosis, and leaf distortion [91–93]. Usually, this virus does not cause tree death but it can reduce the yield for example in Anyue, Sichuan Province of China up to 80% lemon production is affected by CYVCV and yield is reduced by 50–80% [89].

2.2.4 Management

2.2.4.1 Biological control

The biological control of CWF is poorly studied but it includes mainly the use of potential predatory insects. The main natural enemies of CWF include representatives of predatory coccinellid with highlight to *Serangium japonicum* Chapin (Coleoptera: Coccinellidae). This natural enemy has been reported in pesticide-free crops with many CWF, in the Japan with peaks in May and July reducing the CWF number in the second peak [94]. Release of another ladybird beetle *S. parcesotum* Sicard (Coleoptera: Coccinellidae) in the East Mediterranean region reveals that the predator has success in the colonization of orchards with potential to control CWF [77, 95]. Some parasitoids also have potential to control CWF, including *Encarsia lahorensis* (Howard) (Hymenoptera: Aphelinidae), and *Eretmocerus debachi* Rose and Rosen (Hymenoptera: Aphelinidae) [96–98] but further studies to optimize the control are necessary. Likely parasitoids, pathogenic agents are also poorly evaluated. The fungus *Aschersonia placenta* Berkeley and Broom (Hypocreales: Clavicipitaceae) isolates were evaluated in China and three of them have potential to control CWF [82]. In addition, *A. aleyrodis* Webber (Hypocreales: Clavicipitaceae) was reported causing high mortality in *D. citri* at Southern Alabama and China [99]. *Lecanicillium attenuatum* Zare and Gams from order Hypocreales have also been reported to kill the nymphs of CWF, thus considered a potential biological control agent of this pest [100, 101].

2.2.4.2 Physical control

Physical control involving the use of ultraviolet (UV) light to control insects mainly CWF is gaining importance as one of the components of IPM because this technique is environmentally benign and non-hazardous to non-target organisms [102–105]. Traps designed with UV releasing tubes can be installed in the field to monitor and reduce the population of CWF as adults of this pest exhibit positive phototactic behavior to UV source [102, 106, 107]. UV light kills the captured insects by inducing oxidative stress and altering some life traits such as behavior, developmental patterns, and biochemistry [108–110]. Exposure of CWF for longer period, for example, about seven hours per day, can decrease the fecundity, and oviposition rate. Moreover, pupal formation, longevity of adult females, and adult emergence have also been reported to decrease significantly in CWF upon exposure to UV light [107]. Apart from UV light, colored sticky cards and yellow sticky traps should also be used during the active season of CWF in orchards to detect, monitor, and control the insect population as a part of IPM [111, 112].

2.2.4.3 Cultural control

All the practices in citrus orchard that enhance the passage of air flow through the canopy of citrus trees come under the cultural control, these practices include the following: maintaining a proper plant to plant and row to row distance, weed eradication, light to moderate pruning, and optimum application of irrigation and fertilizer. These cultural practices do not allow humidity among the trees to increase significantly and thus keep the population under check [113, 114].

2.2.4.4 Chemical control

Chemical control using inorganic compounds, botanicals, and synthetic insecticides is an integral part of IPM for the control of CWF; however, it should be used judiciously and only when required. Two applications of summer oil or white oil (petroleum) emulsion are recommended during peak activity of CWF; however, in case of very high populations density spray can be done 3–4 times, Refs. [113–115] suggested that use of pyriproxyfen or buprofezin @0.05% twice with the span of 45 days can give good control of CWF in citrus orchards. The joint application of an organophosphate insecticide triazophos and neem formulation can suppress the nymphs and adults of CWF if sprayed twice at 15-day interval in the citrus orchards [116]. Use of tree spray oil (0.5 and 1%) along with lime sulfur diluted with water can provide satisfactory control of CWF eggs mainly in the orchards of sweet oranges. Moreover, significant nymphal control of CWF can be achieved by spraying 0.03% dimethoate and formothion [117]. Sole reliance upon conventional chemical control of CWF should be avoided as this pest can develop resistance quickly to different pesticides render them ineffective [118, 119].

2.3 Citrus mealybug

The scientific name of citrus mealybug (CMB) is *Planococcus citri* (Risso) and this species belongs to order Hemiptera and family Pseudococcidae.

2.3.1 Distribution

CMB is polyphagous and most destructive pest of citrus orchards and nurseries. It is distributed in different parts of the world such as in Egypt [120], Florida [121], California [122], Portugal [123], Turkey [124], South Africa [125], USA [126], South pacific region [127], Australia [128, 129], India [130], Mediterranean region [131, 132], America [122, 133], and Pakistan [134].

2.3.2 Eco-biology

Sexual dimorphism occurs in CMB [135]. The female of CMB has oval, flat, and soft body, which is covered with wax and long waxy filaments [136]. The length of adult female insect is about 3 mm [135]. Similar to other scale insects, females of CMB are wingless [137]. Female lays yellow eggs within ovisacs in soil and each ovisac contains about 300–800 eggs. About 10–20 days are required to egg hatching. After hatching, the amber colored nymphs emerge and start feeding by inserting the mouthparts in the lower side of leaves epidermis. The female molts three time to become an adult and complete its nymphal duration in six to eight weeks. The male is gray, winged, and midge like and has long antennae but no mouthparts (**Figure 2**) [138]. Adult males are 1 mm in length and have two caudal filaments [135]. In its early stage, male resembles with female but as it grows, male secretes fibrous, cottony cocoon from which adult male emerges [139]. The male nymphal instars molt 4 times until adult [138]. During winter, they hide themselves in cracks and cavities in tree trunks in the adult female or egg stage. In late spring according to the temperature, especially at the end of April or beginning of May (early summer), they emerge from hibernating sites. CMB has about three to six overlapping generations per year but the Spring-Summer life cycle is major concern for citrus growers as peak infestation occurs in the month of June in Mediterranean region of the Turkey [140]. The males of CMB exhibit the phenomena of polygyny and can fertilize multiple females during their short life span [141, 142]. Generally, the sperm from younger males has more chances to fertilize the female eggs [143].

2.3.3 Damage

The CMB has potential to cause high loss in agriculture especially in citrus and grapevine industry. The CMB infestation causes direct and indirect type of damage to citrus orchards [144]. All parts of tree such as new leaves, stem, flowers, and fruits are damaged by CMB except underground portion of the plant. The CMB (nymphs and adult female) sucks the sap from different parts of plant, which results in defoliation (about 80%), wilting, dropping of fruits and flowers, deformed fruit appearance [132], and premature yellowing and causes approximately 95% loss in crop yield [145, 146]. In case of heavy infestation, stunting and death of plants occur [136]. According to Smith et al. [128], in South Africa, the early ripening cultivars are more susceptible to damage by CMB than the late maturing cultivars. In early ripening cultivars, the natural enemies have less opportunity to suppress the pest population of CMB in the field before harvesting stage. Generally, fruit damage is caused by CMB between petal fall and at that time when fruits are size of golf ball [147]. The indirect damage to plant by CMB is the production of copious amount of honeydew on foliage and fruits, which provides the growth medium for development of sooty mold fungus [145]. Sooty mold is dark superficial coating on different parts of plants, which decreases the photosynthetic capacity of plant by reducing the amount of light entering the leaf cells; the presence of this black mass upon harvested fruit ultimately reduces the market value [144]. Honeydew is also source of food for ants, which may protect the CMB from their natural enemies [148].

Figure 2.
Planococcus citri *adult male having membranous wings and tail filaments (A), cottony ovisac with egg mass deposited by adult female of* P. citri *(B), nymphs, pre-pupae and pupae of* P. citri *(C) and adult female of* P. citri *whose body is covered with white powdery mass (D). Photographs by lance S. Osborne, the University of Florida, USA (A), Lyle J. buss, University of Florida, USA (B) Paul J. Johnson, South Dakota State University, USA (C) and William Bodine in 1455 N Val vista Dr., Mesa, AZ 85213, USA captured on august 19 2022 (D).*

2.3.4 Management

2.3.4.1 Mechanical and cultural control

During winter, pruning of infested parts is recommended as it allows sufficient light penetration in the canopy, and thus helps in exposing the hibernating insects which are ultimately killed by natural enemies and solar light. Pruning as prophylactic approach is also best management option to prevent the attack of CMB in next season [10, 149]. Some ant species in the citrus orchards hinder the success of biological control of CMB by disrupting the activity of predators and parasitoids and they also act as mechanical carrier for mealybugs and transport them to their feeding sites [148]. Therefore, destruction of the ant colonies in citrus orchards is suggested to disrupt the mutualism between ants and CMB [10, 128, 137]. Plowing the soil near tree trunk during summer to expose the eggs and females to their natural enemies and sunlight is also best technique to control this pest. The sticky bands of 7–8 cm should be wrapped around trunk during second week of December at the height of 0.5 m from ground. The population of CMB can also be controlled by removing the bark as it helps in the elimination of harboring sites of CMB nymphs [150].

2.3.4.2 Use of host plant resistance

The tolerance/resistance against insect pest is also important phenomena and has been observed in three citrus cultivars *viz.*, *Citrus limon*, *C. macroptera,* and *C. grandis* against the attack of CMB. Therefore, these cultivars should be used as rootstock in management program against CMB. *C. sinensis* and *C. limettiodes* have been found moderately resistant to the attack by CMB and only suffer 20.65–30% leaf infestation [151].

2.3.4.3 Biological control

2.3.4.3.1 Predators

The mealybug destroyer *Cryptolaemus montrouzieri* Mulsant (Coleoptera: Coccinellidae) from Australia was introduced into California in 1982, which effectively controlled the CMB infestation in field. This coccinellid predator provides the effective control by reducing the eggs masses, nymphs, and adult population of CMB [152, 153] but Hattingh and Tate [154] found that *C. montrouzieri* is sensitive to IGR, pyriproxyfen, which is used for control of red scales in citrus orchards. It is recommended to release about 500 *C. montrouzieri* beetles per acre in the citrus orchard for effective control [155]. The other most common predators of CMB include *Scymnus syriacus* (Mars.) (Coleoptera: Coccinellidae) and the chrysopid predator, *Chrysoperla carnea* (Stephens) (Neuroptera: Chrysopidae) [156]. Efforts should be made to conserve and enhance the effectiveness of these predators in the orchards by relying less on chemical control.

2.3.4.3.2 Parasitoids

The hymenopteran wasps are most abundant biological control agent for CMB in various regions of the world. The two parasitoids *Leptomastix dactylopii* Howard and *Leptomastidea abnormis* (Girault) (Hymenoptera: Encyrtidae) are used as bio-control insects against CMB [157–159]. However, Mani [160] reported that the indigenous, *Coccidoxenoides peregrines* (Timberlank) (Hymenoptera: Encyrtidae) is more abundant and having parasitism rate of about 10 to 30%. Krishnamoorthy and Singh [161] reported the successful example of release of *L. dactylopii* in India in 1983 on mandarins. Within two month of release, it provided 100% parasitism rate by feeding on all stages of CMB. In South Africa, *C. peregrines* are reared at commercial level and provide good control against CMB [147].

2.3.4.3.3 Pheromone

A synthetic pheromone [(1R-cis)- 2, 2-dimethyl −3-(1-methylethenyl) cyclobutyl methyl acetate] of CMB elicits a positive response against male adults and half-life of this pheromone is about 2 weeks in field and maximum males are caught at the dose of 400–700 mg [162].

2.3.4.3.4 Entomopathogenic nematodes

The entomopathogenic nematodes (EPN) have ability to control the wide range of insect pests including CMB and can be applied as bio-control agent. Once they penetrate inside the host haemocoel and release symbiotic bacteria, the host is killed within 24–48 h. EPN have no negative effect on environment, human, and other vertebrates. The six indigenous species have been used to access the susceptibility of CMB. Three heterorhabditids species (*H. zealandica*, *H. safricana*, and *H. bacteriophora*) and three steinernematids (*S. yirgalemense*, *S. khoisanae*, and *S. citrae*) were evaluated. *The S. yirgalemense* and *H. zealandica* caused highest mortality of about 97 and 91%, respectively, as compared to the other four tested species of nematodes [125], therefore these two species should be incorporated in the biological control program of CMB.

2.3.4.4 Chemical control

The management strategies for control of CMB have been mainly based upon bio-control agents. However, the control with chemical method is most common and widely used strategy because of poor adaptation of natural enemies in varying climatic conditions [10]. The control of CMB by using chemicals can be difficult and effectiveness of chemicals depends on correct application at time when needed. However, acceptable control of CMB may not be achieved with single treatment; the follow-up application of chemicals is necessary. The effective control can be achieved if application is started at the time of initial infestation of pest population [163]. To preserve the natural enemies, it is mandatory to use selective insecticides for control of CMB [164]. Kütük et al. [124] conducted a study to evaluate the effect of biological and chemical control against CMB. They found that summer oil and spirotetramat are compatible with natural enemies, for example, *C. montrouzieri* and *L. dactylopii*, while these natural enemies showed incompatibility with chlorpyrifos-ethyl, due to its side effect on these bio-control agents. Due to cryptic nature and protection with waxy material of CMB, it is necessary to use the chemicals with high vapor pressure. The major insecticides recommended for the control of CMB are from organophosphate (e.g., chlorpyrifos, malathion, dimethoate, azinfos-methyl, dichlorvos parathion, diazinon, and pirimiphos-methyl) and carbamate group (e.g., methomyl, thiodicarb, and carbaryl). These insecticides are applied individually or are mixed with mineral oils [141, 165]. The excessive use of these insecticides for the control of CMB might lead to development of insecticide resistance; therefore, some alternative insecticides such as dinotefuran, acetamiprid, imidacloprid, and thiamethoxam from neonicotinoid group can be employed in the management program of CMB [141].

2.4 Citrus thrips

Citrus thrips is piercing-sucking insect, which belongs to order Thysanoptera and family Thripidae. Various species of phytophagous thrips have been reported upon citrus in the world such as *Scirtothrips citri* (Moulton), *S. aurantii* Faure, *S. dorsalis* (Hood), *S. inermis* Priesner, *Pezothrips kellyanus* Bagnall, *Megalurothrips kellyanus* (Bagnall), western flower thrips *Frankliniella occidentalis* (Pergande), *F. bispinosa* (Morgan), *Thrips major* Uzel, *T. hawaiiensins* Morgan, *T. meridionalis* (Priesner), *T. angusticeps* Uzel, *T. obscuratus* (Crawford), *T. tabaci* Lindeman, *Heliothrips haemorrhoidalis* Bouché, *Chaetanaphothrips signipennis* (Bagnall), and *C. orchidii* Moulton [166–175].

2.4.1 Distribution

Different species of thrips reported on citrus have worldwide distribution. Among all the species, *S. citri* commonly known as citrus thrips or California citrus thrips is of great economic importance in USA and Asia. In USA, it is infesting citrus particularly oranges (Navel oranges), grapefruit, and lemons in California, Arizona, northwestern Mexico, Florida, Washington, and Georgia [174, 176–179]. In Asia, *S. citri* has been recorded in India, China, Iran, and Thailand [179, 180]. Another thrips of economic importance on all type of citrus plantations (lemons, oranges, and grapefruits) is *P. kellyanus*, commonly known as Kelly's citrus thrips (KCT). *P. kellyanus* is Mediterranean in its origin and has been distributed in various geographical regions around the world in Australia [170, 181], New Zealand [182], Southern France [183], Cyprus [171], Italy [184, 185], Spain [186], Turkey, and Greece [187, 188], Portugal [189], Chile [190], Morocco [191], and Tunisia [175].

2.4.2 Eco-biology

Citrus thrips complete their life cycle from egg to adult stage in two to three weeks. The duration of each stage varies with the host species attacked, as well as temperature and humidity of the environment [192]. Citrus thrips is hemimetabolous insect and has following stages: eggs, 1st and 2nd instars or larvae (active feeding immature stages), 1st and 2nd stage pupae (non-feeding instars known as pre-pupa and pupa), and adult or imago (equipped with fringed wings) [176]. The adult female prefers to lay eggs deeply inside the soft and young tissues of leaves, stems, and floral buds with the help of saw-like ovipositor; the egg laying-puncture is completely closed after egg laying. On an average 25–35 eggs are laid per female with maximum of 250 during its life time. Fertilized eggs mostly develop into females and seldom to males. However, only male offspring is developed from unfertilized adult females. Eggs hatch in 5–8 days depending upon the temperature. First and second instars are active feeders and complete their development in 4–14 days by feeding upon soft leaves and under the sepals of tiny fruits. The third and fourth instars known as pre-pupa and pupa, respectively, are passive stages and do not feed, and they spend their time on the ground, tree crevices or inside the curled leaves. Development period from egg to adult formation varies according to temperature such as it requires 16 and 13 days at 25°C and 31°C, respectively. The adult female lives for 26–30 days at 31°C. The number of generations of citrus thrips ranges from 8 to 12 in various agro-climatic conditions. The activity of thrips commence usually in spring and at the beginning of summer at the temperature range of 20–25°C as it coincides with the flowering period and formation of young fruits on trees. The rise in temperature above 30°C and absence of flowers and young fruits result in decrease in thrips population density [175, 177, 193–196].

2.4.3 Damage

Citrus thrips attack usually commence during the flowering stage mostly at petal fall or new fruit formation. Thrips nymphs (1st and 2nd instars) and adults with the help of their asymmetrical piercing-sucking stylet inflict damage to citrus leaves, flowers, buds, and young fruits by extracting the cell contents. Feeding activity upon newly developed citrus flush often results in curling of leaves, along with the appearance of silvery or grayish scars upon the leaves. The damage also results in poor development and growth of infested plant [197–199]. Fruit scarring is the diagnostic damage pattern of citrus thrips, which usually starts when fruit is developing (≤2.5 cm diameter) (**Figure 3**).

Due to thigmotactic nature of citrus nymphs, they prefer to feed under the calyx of young fruit, which results in the development of ring-shaped scar around the calyx or fruit peduncle. In some citrus cultivars such as Navel oranges, thrips activity develops the scaring marks at the styler end of the fruit surface. "Russetymarking" and "tear staining" upon the peel or ring of citrus fruits such as in oranges is also sign of thrips induced damage. Scarring marks are mostly observed upon fruits, which lie outside the canopy. Thrips herbivory upon developing citrus fruits also causes abortion, irregular development or deformity, discoloration, and necrosis of the fruit [200]. Blemishes and scar patterns (cosmetic losses) due to feeding of citrus thrips enormously reduce the market value of citrus fruits leading to export and monetary losses to citrus growers and exporters [184, 201, 202]. Abrasion and scarring of citrus fruits by citrus thrips negatively affects the physiochemical qualities of fruits such as higher percentage of TSS and sugar/acid ratios, lower titratable acidity, increase in water loss, and more rapid weight loss [203].

2.4.4 Management

2.4.4.1 Biological control

The use of predatory mites as biological control agent of citrus thrips is well documented. The most important predacious mites recommended against citrus thrips are phytoseiid mites: *Euseius tularensis* Congdon and *E. hibisci* (Chant) (Acari: Phytoseiidae) and anystid mite: *Anystis agilis* Banks (Acari: Anystidae). These species can be conserved and released in mature citrus orchards and scarring of citrus fruits can be minimized [204–209]. Some other predacious mite species such as *Iphesius* (= *Amblyseius*) *degenerans* Berlese, *Neoseiulus barkeri* (Hughes) (Hughes) (= *Amblyseius mckenziei*), and *N. cucumeris* (Acari: Phytoseiidae) can be used as potential biological control agents against immature thrips in citrus nursery [210]. Another predatory mite *Gaeolaelaps aculeifer* (Acari: Laelapidae) has been shown to successfully reduce the infestation of thrips in commercial citrus orchards of Valencia, eastern Spain after the augmentative release [211].

Figure 3.
Citrus fruit (Kinnow mandarin) infested by thrips showing scarring mark as one of the diagnostic damage patterns. Photograph by Bodil N. Cass, Department of Entomology and Nematology, University of California, Davis, USA.

The use of natural insect predators is advocated for the control of thrips in citrus orchards in different regions of the world. Among the generalist predators of thrips, *Orius insidiosus* (Say) (Hemiptera: Anthocoridae) commonly known as minute pirate bug is an aggressive and voracious predator of thrips adults and nymphs in citrus [173, 179, 212, 213]. Some other generalist thrips predators known are chrysopids, coccinellids, and mirids [214]. Two predatory thrips species *Karnyothrips flavipes* (Jones) and *Leptothrips* spp. have been identified and are known to attack thrips in citrus in Florida, USA [215].

2.4.4.2 Chemical control

Complete thrips control in citrus orchards cannot be obtained merely by biological control agents; therefore, application of different insecticides for the suppression of thrips population below economic damaging levels is unavoidable. The insecticides from organophosphorus (OP), pyrethroids, and new chemical groups are recommended for thrips control. Spray with systemic insecticides at pre-flowering or post-flowering stage is recommended. Dimethoate, a systemic and broad-spectrum OP insecticide, is highly recommended and widely used insecticide against thrips in citrus orchards. It is applied before petal fall when less than 10% buds have opened. Its application on nursery plants is not recommended; however, mature fruits can be sprayed only twice with this insecticide. Among the pyrethroid group insecticides, one application of cyfluthrin or fenpropathrin (broad spectrum) in a year is recommended in the citrus orchards to trees ≤3 years of age. Application of two different pyrethroid insecticides in sequence must be avoided in order to minimize the resistance development. OP and pyrethroid insecticides should be used in rotation as a part of insecticide resistance management tactic. In California, chemical control is initiated when 75 percent petal-fall is complete. In order to minimize the impact of insecticides on natural enemies, and to reduce the resistance development against OP and pyrethroid insecticides, some botanical or microbial nature insecticides such as sabadilla, abamectin, and spinosad should be used for spray. Among the new chemistry insecticides, imidacloprid, acetamiprid, and thiamethoxam from neonicotinoid group and chlorfenapyr from pyrroles group are also recommended against citrus thrips [177, 216–219].

3. Chewing insects

3.1 Citrus leafminer

The scientific name of citrus leafminer (CLM) is *Phyllocnistis citrella* Stainton and it belongs to order Lepidoptera and family Gracillariidae.

3.1.1 Distribution

The CLM is a most destructive pest of citrus nurseries, top grafting trees, and also citrus growing in plastic greenhouses in various parts of the world [220]. This pest is native to eastern and southern Asia occurring in China, India, Thailand, Japan, and Vietnam [221, 222]. It was reported in southern Florida in 1993 [223, 224], most of Caribbean region and Southern part of USA [225, 226]. It has also been reported in Northern part of South America, Uruguay, and Mediterranean coast of Europe [227], in the Middle East [228], Reunion Island [229], and North Africa [227]. In 1999, its damage was reported from Arizona [230].

3.1.2 Eco-biology

The number of eggs laid per female is about 30–75. The eggs are translucent, white, and appear similar to tiny water droplets. Usually female lays eggs underside of leaves and along the leaf mid-vein toward leaf petiole. Eggs hatch in 2–10 days according to the environmental conditions. CLM has four larval stages and having total developmental time of about 5 to 20 days. Upon hatching, larvae immediately begin mining beneath the epidermal cells. The 1st instar larvae are green in color, translucent, and difficult to detect. The 2nd and 3rd instar larvae are also translucent and yellow-green in color. The 4th instar larvae are clearly visible and form silken cocoon within mines. 4th instar larva curls the leaf edge as silk dries over the cocoon and forming a protective shell called pupa. In initial stage, pupa is yellow-brown in color but at later stage it becomes darker. About 6–22 days are required to complete the pupal duration. The adult is white and has silvery scales on the dorsal surface of forewings and distinctive black spots on the tip (**Figure 4**). The moth is small and of the size of mosquito and active during early morning and evening. The entire life cycle of CLM is completed in 14–50 days depending on temperature of the environment [230].

3.1.3 Damage

The CLM damages the trees by forming mines especially underside of young leaves and the fruit is rarely mined (**Figure 5**). The leaf mining by CLM results in partial chlorosis, necrosis, leaf deformation, and ultimately causes defoliation, which reduces the photosynthetic activity of plants. The mining in spring flush causes more damages as it is responsible for fruit development than that of fall flush. Besides this, mining also facilitates the entry point for number of plant pathogens such as bacterial citrus canker. The bacterium *Xanthomonas citri* (Hasse) is the cause of an important disease in citrus plant called Asian citrus canker [231]. The canker-infected tree produces lesions on leaves, stems, and fruits, which results in defoliation, fruit drop, blemishing on fruit, twig dieback, and general tree decline [232–234].

3.1.4 Management

3.1.4.1 Chemical control

Many farmers apply insecticides to mitigate the effect of CLM as they see visual impact of foliar damage on trees. This control measure is expensive and often ineffective because none of product provides long-term control than just for two week [235, 236]. To control the CLM, the chemical control is often inappropriate strategy because of high cost to manage the pest, risk of development of resistance in pest population, accumulation of pesticides residues in food and also in ground water, effect on natural control agents, harmful effect on field workers, and also to environment [237]. Tan and Huang [238] also reported development of resistance to pesticides in CLM.

Figure 4.
Adult stage of Phyllocnistis citrella *with distinct black spots at the dorsal surface of both forewing and hindwing. Photograph by Jack Kelly Clark, University of California, Statewide IPM program.*

Figure 5.
A newly developed leaf of Kinnow mandarin is under the infestation of three larvae of Phyllocnistis citrella. *Feeding of larvae upon leaf tissues results in the development of prominent mines, which is one of the diagnostic damage patterns of* P. citrella. *Photograph was taken by Dr. Muhammad Babar Shahzad Afzal at citrus nursery of Citrus Research Institute, Sargodha, Punjab, Pakistan on August 29, 2017.*

3.1.4.2 Monitoring using traps

Pheromones traps should be used to determine pest population abundance in field. However, control decision is based on sampling of active larvae. Usually, monitoring should be done in February through May and September–October, at that time 50% of trees are actively flushing. Randomly ten leaves are selected and live larvae are observed with hand lens. The young trees should be treated when 30% of leaves have active mines with live larvae, while older trees are treated unless severely damaged.

3.1.4.3 Cultural practices

In the irrigated areas of citrus production, CLM population might be suppressed by modifying the trees to produce alternate flushing by managing the irrigation and fertilizer application but it is not possible in areas where summer rainfall is too high such as Florida's subtropical climatic conditions. Other management options such as development of host plant resistance also do not provide long-term control and there is no clear evidence that varieties are resistant to attack of CLM. The water sprouts usually develop on branches and above grafting on tree trunk and rapidly produce the new flushes for long period of time. Removal of such water sprouts is crucial because it provides sites for oviposition. Besides this, the water sprouts below root stock should also be removed as they do not produce desirable fruits [239].

3.1.4.4 Biological control

The biological control agents of CLM play an important role in keeping the pest population below economic injury level. According to one report, 60% population of CLM was killed by its predators and parasitoids in Yuma. The common parasitoid *Cirrospilus coachellae* Gates (Hymenoptera: Eulophidae) appears in late summer and early fall and effectively controls the CLM. The Yuma spider mite and *Tydeu* ssp. have been reported to feed on CLM larvae [230]. Browning et al. [240] and Pena et al. [241] also identified some parasitoids of CLM {(*Cirrospilus* sp., *Pnigalio minio* (Walker), *Sympiesis* sp., *Elasmus tischeriae* (Howard), *Closterocerus cinctipennis* Ashmead, *Horismenus* sp., and *Zagrammosoma multilineatum* (Ashmead)} in Florida during 1993–1994. The level of parasitism varies ranging up to 60%. The lowest parasitism level was recorded in late winter and early spring. Similarly, some predators have also been found to attack the CLM which include *Chrysoperla rufilabris* (Burmeister), *Solenopsis invicta* (Buren), predatory thrips and some spiders [242].

3.2 Lemon butterfly

The scientific name of lemon butterfly (LBF) is *Papilio demoleus* Linnaeus and it belongs to order Lepidoptera and family Papilionidae.

3.2.1 Distribution

The rapid dispersal ability and population growth of LBF makes it economically serious pest with its distribution in different parts of the world such as Pakistan [243], Iran, Formosa, Japan, India, China [244], Bangladesh [245], United States [246], Southern Asia [247]), Island of Hispaniola [248], Iraq [249], Middle East [250, 251], Indonesia [252–254], New Guinea [255], and Australia [256, 257].

3.2.2 Eco-biology

According to Xingyong et al. [258], in warmer temperate region of China, LBF has five generations per year. This pest completes its life cycle in about over 30 days [6]. The eggs of LBF are round, having smooth surface and yellow-white in color [259]. The eggs are laid either singly or in group of 8–10 on the lower surface of leaves or twigs within 2–3 days post-mating. The hatching of eggs occurs in 4–5 days. There are five larval stages with developmental time ranging from 27 to 35 days [6]. The final larval stage is ready to form a pupa. Larvae of this stage secrete watery and soft stool as compared to grainy or dry stools produced by other stages. During the onset of pupal formation, the body of last larval instar is compressed and it produces silken thread, which is used to fasten and anchor the new developing pupa with some substratum. This stage can be called as pre-pupa. For 15–18 hours, larvae are in fixed position and shed their dried skin to form a pupa which requires 10–12 days to complete its development. When viewed from lateral part, it looks alike torpedo-shaped [260]. Both female and male adults of LBF are black with yellow or whitish marking in wings (**Figure 6**) [245]. The adults can survive 7–12 days after emergence from pupae [6]. In February (late winter), the population of LBF started to increase and reaches at peak level in April–May (late spring to early summer) and subsequently declines till September (autumn). The second peak starts at the end of September (mid-autumn) and again population flurry-up but the second peak is much smaller than the first one [245].

3.2.3 Damage

LBF is one of the major and economic pests of citrus [6, 261]. The citrus plant is damaged by only larval stage which devours the large quantity of foliage. It is voracious feeder and causes serious damage to young seedling, nurseries and also has capability to cause defoliation; thus, LBF is a potential threat to citrus growers (**Figure 7**) [262]. It can cause up to 83% defoliation in young trees in case of severe and unchecked infestation [263]. The LBF has wide ecological tolerance which enables it to thrive in different environmental conditions [264].

3.2.4 Management

3.2.4.1 Biological control

Winotai and Napompeth [265] performed a survey of natural enemies of LBF in Thailand. The *Ooencyrtus malayensis* and *Tetrastichus* sp. were found to parasitize the egg stage. There are some predators which affect the larval stage such as *Proxys punctulatus*, *Podalonia sp*, bird (*Oriolus steerii*) and spider (*Nephila sp.*) [266]. The insect parasitoids such as *Erycia nymphalidophaga* [265], *Apanteles papilionis,* and *Bracon hebetor* [267] have been reported as larval parasitoid of LBF. The parasitoids which affect the pupal stage of LBF are *Brachymeria sp* and *Pteromalus puparom*.

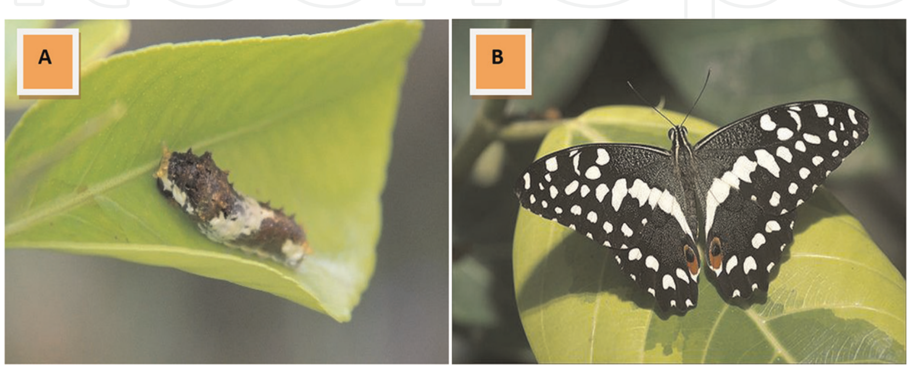

Figure 6.
Early instar larva (A) and adult (B) of Papilio demoleus*. Photographs by https://momsmeanderings.wordpress.com/2017/02/02/lifecycle-of-a-citrus-swallowtail-butterfly/ (A) and Foto Martein in the indoor butterfly garden "Jardins des Papillons" in Hunawihr, Alsace, France on June 22, 2007 (B).*

Figure 7.
Late instar of Papilio demoleus *feeding and cutting the leaf edges of citrus plant. Source: https://momsmeanderings.wordpress.com/2017/02/02/lifecycle-of-a-citrus-swallowtail-butterfly/.*

3.2.4.2 Insecticidal control

3.2.4.2.1 Botanical insecticides

The botanical insecticide is an alternative to synthetic insecticide for the management of pests as it provides little or no threat to the environment, ecosystem, and human health [268]. The antifeedant activity of azadirachtin was evaluated against LBF larvae [269], azadirachtin is most important natural antifeedant, which inhibits the feeding and indirectly causes death of insect due to starvation [270]. Another approach to spray the plant leaves is with distasteful substance derived from plant extracts. According to Vattikonda et al. [271], forskolin, a labdane diterpene derived from the plant *Coleus forskohlii* showed an antifeedant activity at the concentration of 200 ppm. Similarly, betulinic acid from *Ziziphus jujube* [271] and andrographolide from *Andrographis paniculate* [272] also displays strong antifeedant activity against LBF.

3.2.4.2.2 Microbial insecticides

The pathogen can be used as biological control agent and is integrated with natural enemies to protect the crop from insect pest damage. The isolates of *Isaria fumosorosea* (Ifr_1 and Ifr_2) showed their potential to kill the LBF larvae by causing 72.23 and 61.90% mortality after exposure of 8 days at dose of 10^8 spores/ml concentration, respectively [273]. The one of most commonly used microorganism is *Bacillus thuringiensis* (Bt), which is highly effective against lepidopteron larvae [274]. Osouli and Afsharmanesh [275] found that a strain of *Bacillus subtilis* (M419) produces secondary metabolites especially lipopeptide biosurfactants that inhibit the growth and cause larval mortality in LBF.

3.2.4.2.3 Synthetic insecticides

The synthetic pesticides are used in large scale for control of insect pests worldwide because of high efficacy and low cost. However, the regulation of these compounds is also increasing globally due to their concern about toxicity and environmental safety [276]. The cypermethrin has been proven more toxic for larvae of LBF than that of neem extract of *Azadirachta indica*, while deltamethrin was found less effective than *Azadirachta*; hence, cypermethrin could be a good candidate against LBF in citrus orchards [277]. Haque et al. [278] reported that LBF treated with spinosad and chlorfenapyr showed lowest rate of infestation, hence are highly effective and their use could result in highest yield of citrus due to significant suppression of LBF. The application of spinosad is environmentally benign and cost effective than that of chlorfenapyr. It can be suggested that grower should use spinosad for the management of LBF larvae in nurseries and gardens. The juvenile insect growth regulator (IGR) known as diofenolan which severely hampers the normal development, growth, and metamorphosis of LBF larvae can also be incorporated in IPM for better control [279]. Another IGR known as diflubenzuron is also effective in controlling the LBF; it not only reduces the growth but also causes morphological deformities in insect [280].

3.2.4.3 Mechanical control by hand picking

The hand picking is most practical technique under certain conditions such as in case of cheap labor availability, conspicuous, and large egg masses, when insects are too sluggish, have congregate behavior and easily accessible to the pickers. Hand picking of LBF larvae is efficient method to reduce the infestation particularly in nurseries and home gardens [281].

4. Concluding remarks

In this chapter, important features of the main citrus pests were demonstrated. Nowadays, there are many insects that are pests of citrus and a few ones were well-studied, reinforcing that other species need to be investigated. Thus, the studies on biology, ecology, and management of citrus pests are necessary, mainly those that may produce data useful to control and mitigate damages caused by the pests. In addition, field effectiveness and climatic adaptations in different geographic regions with high citrus crop activity should be evaluated in order to contribute for pest control. Furthermore, the search for environmental friendly new molecules, natural enemies, resistant plants, and technological approaches should be stimulated.

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